ARIZONA DEPARTMENT OF TRANSPORTATION

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HIGHWAY DRAINAGE DESIGN MANUAL
HYDROLOGY
METRIC EDITION

Final Report

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METRIC (SI*) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	2.54	centimeters	cm
ft	feet	0.3048	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	6.452	centimeters squared	cm^2
ft^2	square feet	0.0929	meters squared	m^2
yd^2	square yards	0.836	meters squared	m^2
mi^2	square miles	2.59	kilometers squared	km^2
ac	acres	0.395	hectares	ha
		MASS (weight)		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg
		VOLUME		
fl oz	fluid ounces	29.57	millimeters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.0328	meters cubed	m^3
yd^3	cubic yards	0.765	meters cubed	m^3

Note: Volumes greater than 1000 L shall be shown in m^3.

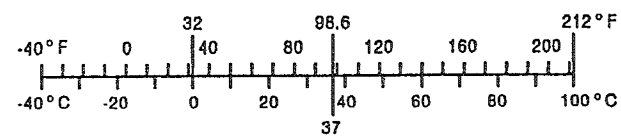
Symbol	When You Know	Multiply By	To Find	Symbol
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

These factors conform to the requirement of FHWA Order 5190.1A

*SI is the symbol for the International System of Measurements

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
yd	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	millimeters squared	0.0016	square inches	in^2
m^2	meters squared	10.764	square feet	ft^2
yd^2	kilometers squared	0.39	square miles	mi^2
ha	hectares (10,000 m^2)	2.53	acres	ac
		MASS (weight)		
g	grams	0.0353	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams (1000 kg)	1.103	short tons	T
		VOLUME		
mL	millimeters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	meters cubed	35.315	cubic feet	ft^3
m^3	meters cubed	1.308	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



PREFACE TO THE METRIC EDITION

The Highway Drainage Design Manual, Hydrology, was originally produced with English units of measurement (dated March 1993 with revisions dated April 1994). The Metric Edition is essentially the same manual, but with numeric values in metric units of measurement.

The Highway Drainage Design Manual, Hydrology, is intended to provide guidance for the performance of flood hydrology for Arizona Department of Transportation (ADOT) drainage design. Two analytic methods are presented, herein, to determine design discharges, and those two methods are to be used mainly for ungaged watersheds. The two analytic methods are; (1) the Rational Method that can be used for uniform drainage areas that are not larger than 160 acres in size, and (2) rainfall-runoff modeling for any size drainage area. The rainfall-runoff modeling guidance is structured to be compatible with the HEC-1 Flood Hydrology program by the U.S. Army Corps of Engineers. For rainfall-runoff modeling, this manual should be used in conjunction with the HEC-1 Users Manual, and the contents of this manual assumes a familiarity and basic understanding of the HEC-1 program and modeling procedures.

A flood frequency analysis procedure is provided for computing flood magnitude-frequency relations where systematic stream gaging records of sufficient length are available. The flood frequency analysis procedure can be used, where appropriate, to (1) estimate the design flood peak discharge, (2) provide estimates of flood peak discharges for the calibration or verification of rainfall-runoff models, (3) provide regional estimates of flood magnitudes that can be used to check or substantiate other methods to estimate flood magnitudes or to develop regional flood discharge relations, or (4) perform other hydrologic studies, such as the investigation of flood magnitudes from snowmelt to be used as baseflow to a watershed rainfall-runoff model.

Three indirect methods are presented for estimating flood peak discharges. Results by either analytic methods or flood frequency analysis should always be compared and evaluated by indirect methods. There may be cases where the flood discharges by all three methods (analytic, flood frequency analysis, and indirect) can be obtained and compared prior to making a selection of design discharge.

This manual was prepared for use by engineers and/or hydrologists that are trained and experienced in the fundamentals of hydrology in general, and flood hydrology in particular.

Other users should work under the direct supervision and guidance of appropriately qualified personnel.

The information in the manual is presented in the following Sections and Chapters:

SECTION I - RAINFALL

Chapter 1 - Rainfall Procedures and instructions are provided to prepare rainfall input to the HEC-1 program, and to generate intensity-duration-frequency curves for use with the Rational Method.

SECTION II - RATIONAL METHOD

Chapter 2 - Rational Method Procedures and instructions are provided for using the Rational Method. This includes two general intensity-duration-frequency curves, a time of concentration equation, and graphs for the selection of the runoff coefficient.

SECTION III - RAINFALL-RUNOFF MODELING

Chapter 3 - Rainfall Losses The method to be used to estimate rainfall losses by the Green and Ampt equation is presented.

Chapter 4 - Unit Hydrographs The Clark unit hydrograph is recommended and procedures to calculate the unit hydrograph parameters are presented.

Chapter 5 - Channel Routing Recommendations and instructions for channel routing are presented.

Chapter 6 - Storage Routing Recommendations and instructions for storage routing are presented.

Chapter 7 - Transmission Losses A discussion of channel transmission losses and guidance on when to incorporate transmission losses into a rainfall-runoff model are presented.

Chapter 8 - Modeling Technique and General Guidance for Using HEC-1 Applicability, assumptions and limitations of the HEC-1 program, general guidance for watershed modeling, and a modeler's/reviewer's checklist are provided.

SECTION IV - FLOOD FREQUENCY ANALYSIS

Chapter 9 - Flood Frequency Analysis Procedures and instructions are provided, along with worksheets and graph paper, for performing graphical flood frequency analyses. A procedure for placing confidence limits about the flood frequency line is provided.

SECTION V - INDIRECT METHODS FOR DISCHARGE VERIFICATION

Chapter 10 - Indirect Methods for Discharge Verification Three methods are presented for checking and "verifying" peak discharges that are obtained by the analytic methods (Rational Method and rainfall-runoff modeling), and by flood frequency analysis.

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CHAPTER 1
RAINFALL

1.1 INTRODUCTION

1.1.1 General Discussion

Analytic methods (Rational Method and rainfall-runoff modeling using the HEC-1 program) require the definition of the rainfall for the desired flood frequency. For the Rational Method, a rainfall intensity-duration-frequency (I-D-F) graph is required. Generalized I-D-F graphs for 2 zones in Arizona are provided for the Rational Method (Chapter 2). There may be situations when a site-specific I-D-F graph is to be used with the Rational Method, and a procedure for developing a site-specific I-D-F graph for any location in Arizona is presented in this section.

For rainfall-runoff modeling (HEC-1 program), the temporal and spatial distribution of the design rainfall must be provided. For highway drainage studies in Arizona, a symmetric nesting of rainfall depths for specified intra-storm durations is used. That rainfall distribution is called the hypothetical distribution, and when using the HEC-1 program, input is provided in the PH record. The point rainfall depth-duration-frequency (D-D-F) statistics that are input in the PH record are automatically adjusted for the rainfall depth-area relation by procedures built into the HEC-1 program. The hypothetical distribution methodology is described in U.S. Army Corps of Engineers, Training Document No. 15 (1982).

1.1.2 Source of Design Rainfall Information

The rainfall depth-duration-frequency statistics for Arizona are derived from information in NOAA Atlas 2, Volume VIII, Arizona (Miller and others, 1973). The short-duration (less than 1-hour) rainfall ratios are from Arkell and Richards (1986). The depth-area reduction curves are those from the NOAA Atlas 2. The NOAA Atlas 2 presents point rainfall depth-duration-frequency values as isopluvial maps in English units. Therefore, it is necessary to convert the rainfall depths from the NOAA Atlas 2 from English units, in inches, to metric units, in millimeters.

1.2 PROCEDURE

1.2.1 General Considerations

Rational Method - When using the Rational Method, either one of the two generalized I-D-F graphs, one for Zone 6 and one for Zone 8 (see Chapter 2 - Rational Method), or a site-specific I-D-F graph is used. The T-year, 1-hour rainfall depth is used with the Rational Method, where T indicates the desired design flood return period.

HEC-1 Modeling - When using the HEC-1 model, the rainfall input is provided in the PH record. The storm duration to be used depends on the total watershed area as follows:

1. If the total watershed area is less than or equal to 2.5 square kilometers, the design storm duration is 6 hours.

2. If the total watershed area is greater than 2.5 square kilometers, the design storm duration is 24 hours.

Arkell and Richards (1986) determined that the short-duration (less than 1-hour) rainfall ratios, as shown in the NOAA Atlas 2 series, are not appropriate for the entire western United States. They identified zones that have different short-duration rainfall ratios and provided those ratios for each zone. Arizona contains two zones (Zone 6 and Zone 8) as shown in **Figure 1-1**. The short-duration rainfall ratios for those two zones are shown in **Table 1-1**. Use of those ratios will affect the short-duration rainfall depths and rainfall intensities as compared to the values that would be obtained using the ratios in the NOAA Atlas 2. The short-duration rainfall ratio from Arkell and Richards (1986) along with the isopluvial maps and other information from the NOAA Atlas 2 are used to define design rainfall for Arizona.

FIGURE 1-1

SHORT-DURATION RAINFALL RATIO ZONES FOR ARIZONA

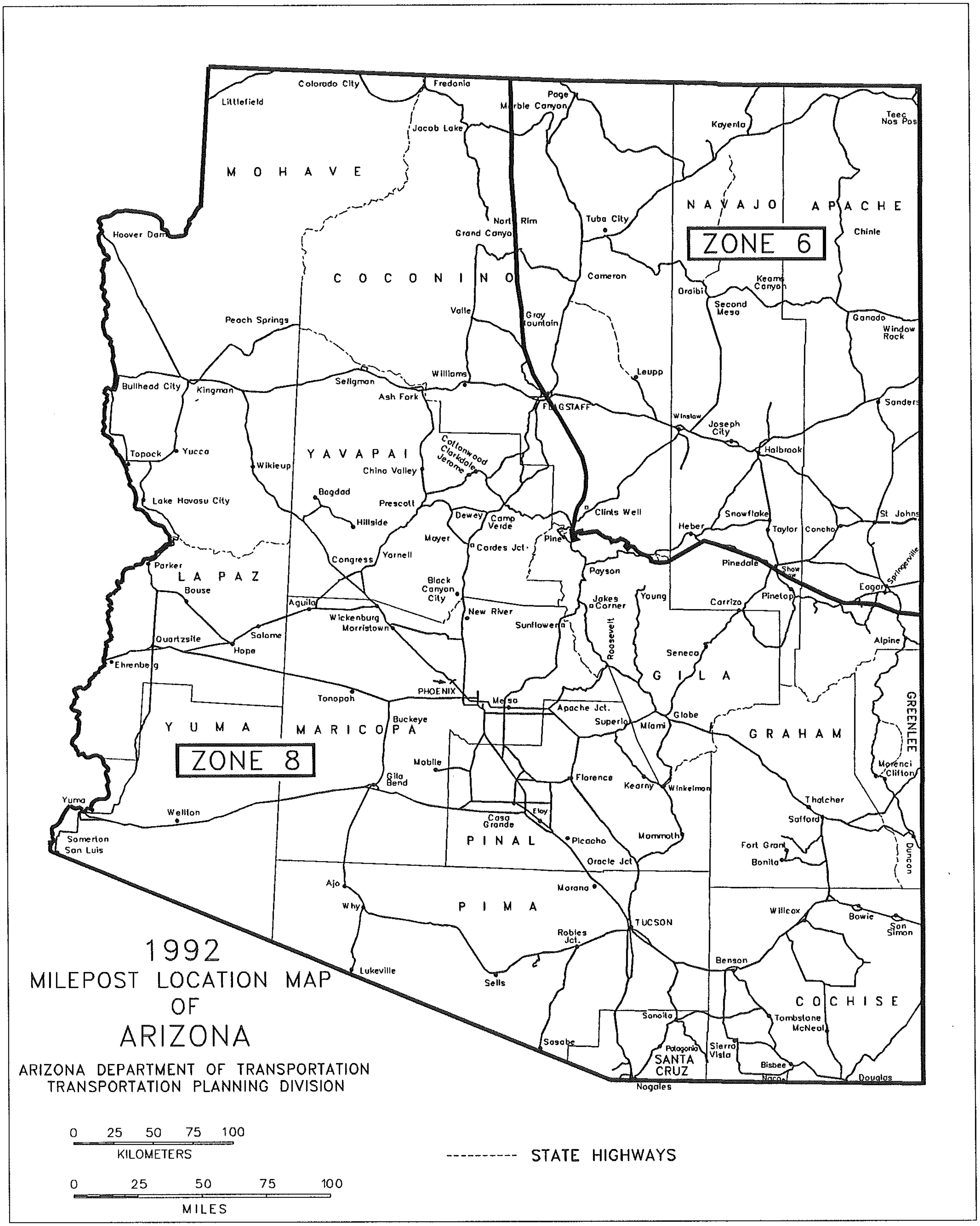


TABLE 1-1

SHORT DURATION RAINFALL RATIOS FOR ARIZONA
(Arkell and Richards, 1986)

	RATIOS TO 1-HOUR RAINFALL DEPTH							
	2-Year Return Period				100-Year Return Period			
	Duration, in minutes				Duration, in minutes			
Zone	**5**	**10**	**15**	**30**	**5**	**10**	**15**	**30**
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
6	.35	.54	.65	.83	.32	.50	.62	.81
8	.34	.51	.62	.82	.30	.46	.59	.80

A rainfall depth-duration-frequency (D-D-F) table must be developed prior to coding input in the PH record or developing a site-specific I-D-F graph. The D-D-F statistics can be calculated by use of the PREFRE Program (U.S. Bureau of Reclamation, 1988) (with input in English units and the conversion of results to metric units) or by the following procedure and equations:

1. Determine the following point rainfall depth-duration-frequency values for the watershed using the isopluvial maps in **Appendix B:**

   a. 2-year, 6-hour ($P_{2,\ 6'}$)
   b. 2-year, 24-hour ($P_{2,\ 24'}$)
   c. 100-year, 6-hour ($P_{100,\ 6'}$)
   d. 100-year, 24-hour ($P_{100,\ 24'}$)

   Note: 5" denotes 5 minutes, etc.
   1' denotes 1 hour, etc.

   1. If the watershed is small or if there is little variation in the isopluvial lines for the drainage area, then the rainfall values can be taken from the isopluvial maps at the centroid of the watershed. If the watershed is large enough to indicate significant variation in rainfall depth throughout the watershed, calculate the area weighted rainfall values. Area- weighted rainfall values are calculated by laying a transparent watershed map and grid over each of

the isopluvial maps. The point rainfall values are read at each grid intersection (a minimum of 10) and these are averaged.

2. For watersheds that are to be divided into modeling subbasins and which contain numerous isopluvial lines (nonuniform rainfall characteristics), consideration should be given to developing separate D-D-F tables for each modeling subbasin. Multiple PH records (one for each subbasin) would be used in the HEC-1 model to improve the distribution of rainfall over the watershed.

2. Convert the point rainfall depth-duration-frequency values from inches to millimeters by the following:

$$P_{T,t} \text{ in millimeters} = (25.4)\, P_{T,t} \text{ in inches}$$

3. Compute the following rainfall statistics:

a. 2-year, 1-hour $\quad P_{2,1'} = -0.279 + \dfrac{.942\ (P_{2,6'})^2}{P_{2,24'}}$

b. 100-year, 1-hour $\quad P_{100,1'} = 12.55 + \dfrac{.755\ (P_{100,6'})^2}{P_{100,24'}}$

4. Compute the following rainfall statistics:

a. 2-year, 2-hour $\quad P_{2,2'} = .341\ (P_{2,6'}) + .659\ (P_{2,1'})$

b. 2-year, 3-hour $\quad P_{2,3'} = .569\ (P_{2,6'}) + .431\ (P_{2,1'})$

c. 2-year, 12-hour $\quad P_{2,12'} = .500\ (P_{2,6'}) + .500\ (P_{2,24'})$

d. 100-year, 2-hour $\quad P_{100,2'} = .341\ (P_{100,6'}) + .659\ (P_{100,1'})$

e. 100-year, 3-hour $\quad P_{100,3'} = .569\ (P_{100,6'}) + .431\ (P_{100,1'})$

f. 100-year, 12-hour $\quad P_{100,12'} = .500\ (P_{100,6'}) + .500\ (P_{100,24'})$

Note: 5" denotes 5 minutes, etc.
1' denotes 1 hour, etc.

5. Determine the short-duration rainfall zone, **Figure 1-1**.

6. Determine the 2-year and 100-year short-duration rainfall ratios, **Table 1-1.**

7. Compute the short-duration rainfall statistics according to the following:

			Zone 6	Zone 8
2-yr, 5-min	$P_{2,5"}$	=	.35 $(P_{2,1'})$	.34 $(P_{2,1'})$
2-yr, 10-min	$P_{2,10"}$	=	.54 $(P_{2,1'})$	.51 $(P_{2,1'})$
2-yr, 15-min	$P_{2,15"}$	=	.65 $(P_{2,1'})$	.62 $(P_{2,1'})$
2-yr, 30-min	$P_{2,30"}$	=	.83 $(P_{2,1'})$	.82 $(P_{2,1'})$
100-yr, 5-min	$P_{100,5"}$	=	.32 $(P_{100,1'})$	.30 $(P_{100,1'})$
100-yr, 10-min	$P_{100,10"}$	=	.50 $(P_{100,1'})$	.46 $(P_{100,1'})$
100-yr, 15-min	$P_{100,15"}$	=	.62 $(P_{100,1'})$	.59 $(P_{100,1'})$
100-yr, 30-min	$P_{100,30"}$	=	.81 $(P_{100,1'})$	.80 $(P_{100,1'})$

8. Compute rainfall statistics for other frequencies (T-year) and other durations (t-min/hour) by the following:

   a. 5-year, t-min/hour $P_{5,t} = .674\ (P_{2,t}) + .278\ (P_{100,t})$

   b. 10-year, t-min/hour $P_{10,t} = .496\ (P_{2,t}) + .449\ (P_{100,t})$

   c. 25-year, t-min/hour $P_{25,t} = .293\ (P_{2,t}) + .669\ (P_{100,t})$

   d. 50-year, t-min/hour $P_{50,t} = .146\ (P_{2,t}) + .835\ (P_{100,t})$

   e. 500-year, t-min/hour $P_{500,t} = -.337\ (P_{2,t}) + 1.381\ (P_{100,t})$

   Note: 5" denotes 5 minutes, etc.
   1' denotes 1 hour, etc.

The values derived from the NOAA Atlas 2 are point rainfall depths. These must be converted to equivalent uniform depth of rainfall for the entire watershed, and this is accomplished with a set of depth-area reduction curves. Use of the PH record with the HEC-1 program will result in automatic adjustment of the point rainfall values that are coded into the PH record. Do not convert the point rainfall depths to equivalent uniform depths of rainfall in the PH record or there will be double reduction of the point rainfall depths using this procedure.

1.2.2 Applications and Limitations

The rainfall statistics that are developed by procedures in this section are dependent upon the information that is provided in the NOAA Atlas 2 (Miller and others, 1973). The potential deficiencies of that information are recognized. However, until a similar, comprehensive and accepted source of rainfall information for Arizona becomes available, the NOAA Atlas 2 will be used for highway drainage studies in Arizona.

The hypothetical distribution is a simplified and idealized representation of the temporal distribution of rainfall. It is intended for use to estimate design discharges for highway drainage facilities. It does not necessarily represent the temporal distribution of any historical storm in Arizona. The use of that distribution for design purposes does provide reasonable assurance that design discharges of specified frequency are produced regardless of the size of the watershed.

For very large watersheds (possibly as large or larger than 1,300 square kilometers (500 square miles)), where the time of concentration (T_C) exceeds 24 hours, a longer duration hypothetical distribution (or other project specific distribution) should be developed and used. Procedures for estimating the watershed time of concentration are contained in Chapter 4 - Unit Hydrographs.

In general, the hypothetical distribution can be used, as input to the HEC-1 program, for highway drainage design purposes in Arizona. Similarly, the two generalized I-D-F graphs (see Chapter 2 - Rational Method) can be used with the Rational Method (within the limitations specified in that section) for most small watersheds in Arizona.

1.3 INSTRUCTIONS

1.3.1 HEC-1 Rainfall Input - PH Record

1. Develop the rainfall depth-duration-frequency (D-D-F) statistics for the desired flood frequency using the D-D-F Worksheet **(Figure 1-2)**, or the PREFRE Program.

2. Code the rainfall input in the PH record:

   a. Field 1, PFREQ

      If the analysis is for flood frequency of 2-, 5-, or 10-year, insert the following value in Field 1:

Flood Frequency	Value of PFREQ in Field 1
2-year	50
5-year	20
10-year	10

   For all other flood frequencies, Field 1 is left blank.

   b. Field 2, TRSDA

      Insert the <u>total</u> watershed area (not subbasin area), in square kilometers, in Field 2. For watersheds with non-uniform rainfall characteristics, i.e. those requiring multiple PH records, the <u>total</u> watershed area is to be input to all PH records.

   c. Fields 3 through 10, PNHR(I)

      1) If the total watershed area is less than or equal to 2.5 square kilometers, insert the rainfall depth, in millimeters, for each duration of the selected flood frequency in the appropriate field:

Field	Rainfall Duration
3	5-minute
4	15-minute
5	1-hour
6	2-hour
7	3-hour
8	6-hour

2) If the total watershed area is greater than 2.5 square kilometers, complete Fields 3 through 8, as above, and insert the additional rainfall depths in Fields 9 and 10:

Field	Rainfall Duration
9	12-hour
10	24-hour

1.3.2 Rational Method - Site-Specific I-D-F Graph

This procedure will be used if one of the two generalized I-D-F graphs (see Chapter 2 - Rational Method) is not to be used.

1. Develop the rainfall depth-duration-frequency (D-D-F) statistics for the desired flood frequency or frequencies using the D-D-F Worksheet, **Figure 1-2**, or the PREFRE Program. (When using the PREFRE Program, input is in English units and results must be converted to metric units.)

2. Divide each rainfall depth by its corresponding duration, in hours. Tabulate these rainfall intensities, in millimeters per hour, using the I-D-F Worksheet, **Figure 1-3.**

3. Plot the rainfall intensities for each rainfall frequency versus the rainfall duration, in minutes, on log-log graph paper.

ARIZONA DEPARTMENT OF TRANSPORTATION
HYDROLOGIC DESIGN DATA

Project No. ______________________ TRACS No. ______________________
Project Name ______________________ Date ______________
Location/Station ______________________
Designer ______________________ Checker ______________________

FIGURE 1-2 Sheet 1 of 4
RAINFALL DEPTH-DURATION-FREQUENCY (D-D-F) WORKSHEET

PART A

Determine rainfall depths from the isopluvial maps **(Appendix B)** and convert inches to millimeters:

	Rainfall depth, in inches	**Rainfall depth, in millimeters**
2-year, 6-hour	$P_{2,6'}$ = ________	$P_{2,6'}$ = ________
2-year, 24-hour	$P_{2,24'}$ = ________	$P_{2,24'}$ = ________
100-year, 6-hour	$P_{100,6'}$ = ________	$P_{100,6'}$ = ________
100-year, 24-hour	$P_{100,24'}$ = ________	$P_{100,24'}$ = ________

Note: $P_{T,t}$ in millimeters = (25.4) $P_{T,t}$ in inches

PART B

Compute the following:

2-year, 1-hour	$-0.279 + \frac{.942\,(P_{2,6'})^2}{(P_{2,24'})} = -0.279 + \frac{.942\,(\quad)^2}{(\quad)}$	$P_{2,1'}$ = ______
100-year, 1-hour	$12.55 + \frac{.755\,(P_{100,6'})^2}{(P_{100,24'})} = 12.55 + \frac{.755\,(\quad)^2}{(\quad)}$	$P_{100,1'}$ = ______
2-year, 2-hour	$.341(P_{2,6'}) + .659(P_{2,1'}) = .341(\quad) + .659(\quad)$	$P_{2,2'}$ = ______
2-year, 3-hour	$.569(P_{2,6'}) + .431(P_{2,1'}) = .569(\quad) + .431(\quad)$	$P_{2,3'}$ = ______
2-year, 12-hour	$.500(P_{2,6'}) + .500(P_{2,24'}) = .500(\quad) + .500(\quad)$	$P_{2,12'}$ = ______
100-year, 2-hour	$.341(P_{100,6'}) + .659(P_{100,1'}) = .341(\quad) + .659(\quad)$	$P_{100,2'}$ = ______
100-year, 3-hour	$.569(P_{100,6'}) + .431(P_{100,1'}) = .569(\quad) + .431(\quad)$	$P_{100,3'}$ = ______
100-year, 12-hour	$.500(P_{100,6'}) + .500(P_{100,24'}) = .500(\quad) + .500(\quad)$	$P_{100,12'}$ = ______

Note: 5" denotes 5 minutes, etc.; 1' denotes 1 hour, etc.

RAINFALL DEPTH-DURATION-FREQUENCY (D-D-F) WORKSHEET
(Continued)

PART C

Determine the short-duration rainfall zone (**Figure 1-1**):

Zone = __________

Determine the short-duration rainfall ratios (**Table 1-1**):

Duration (minutes)	Ratio	
	2-Year	100-Year
5	A = ________	E = ________
10	B = ________	F = ________
15	C = ________	G = ________
30	D = ________	H = ________

Compute the following:

2-year, 5-min	(A) ($P_{2,1'}$) = ( ) ( )	$P_{2,5"}$ = ________
2-year, 10-min	(B) ($P_{2,1'}$) = ( ) ( )	$P_{2,10"}$ = ________
2-year, 15-min	(C) ($P_{2,1'}$) = ( ) ( )	$P_{2,15"}$ = ________
2-year, 30-min	(D) ($P_{2,1'}$) = ( ) ( )	$P_{2,30"}$ = ________
100-year, 5-min	(E) ($P_{100,1'}$) = ( ) ( )	$P_{100,5"}$ = ________
100-year, 10-min	(F) ($P_{100,1'}$) = ( ) ( )	$P_{100,10"}$ = ________
100-year, 15-min	(G) ($P_{100,1'}$) = ( ) ( )	$P_{100,15"}$ = ________
100-year, 30-min	(H) ($P_{100,1'}$) = ( ) ( )	$P_{100,30"}$ = ________

Note: 5" denotes 5 minutes, etc.; 1' denotes 1 hour, etc.

FIGURE 1-2
RAINFALL DEPTH-DURATION-FREQUENCY (D-D-F) WORKSHEET
(Continued)

PART D

For any flood frequency (T-yr) other than 2-year or 100-year, calculate the rainfall depth for each rainfall duration (*t*) by the following equation:

$$P_{T,t} = (X)(P_{2,t}) + (Y)(P_{100,t})$$

where X and Y for a selected frequency (T-yr) are:

Frequency (T-yr)	X	Y
5-year	.674	.278
10-year	.496	.449
25-year	.293	.669
50-year	.146	.835
500-year	-.337	1.381

Selected frequency (T-yr) = ________ X = ________ Y = ________

5-min	$(X)(P_{2,5''}) + (Y)(P_{100,5''})$ = ( )( ) + ( )( )	$P_{\_\_,5''}$ = ______
10-min	$(X)(P_{2,10''}) + (Y)(P_{100,10''})$ = ( )( ) + ( )( )	$P_{\_\_,10''}$ = ______
15-min	$(X)(P_{2,15''}) + (Y)(P_{100,15''})$ = ( )( ) + ( )( )	$P_{\_\_,15''}$ = ______
30-min	$(X)(P_{2,30''}) + (Y)(P_{100,30''})$ = ( )( ) + ( )( )	$P_{\_\_,30''}$ = ______
1-hour	$(X)(P_{2,1'}) + (Y)(P_{100,1'})$ = ( )( ) + ( )( )	$P_{\_\_,1'}$ = ______
2-hour	$(X)(P_{2,2'}) + (Y)(P_{100,2'})$ = ( )( ) + ( )( )	$P_{\_\_,2'}$ = ______
3-hour	$(X)(P_{2,3'}) + (Y)(P_{100,3'})$ = ( )( ) + ( )( )	$P_{\_\_,3'}$ = ______
6-hour	$(X)(P_{2,6'}) + (Y)(P_{100,6'})$ = ( )( ) + ( )( )	$P_{\_\_,6'}$ = ______
12-hour	$(X)(P_{2,12'}) + (Y)(P_{100,12'})$ = ( )( ) + ( )( )	$P_{\_\_,12'}$ = ______
24-hour	$(X)(P_{2,24'}) + (Y)(P_{100,24'})$ = ( )( ) + ( )( )	$P_{\_\_,24'}$ = ______

<u>Note</u>: 5" denotes 5 minutes, etc.; 1′ denotes 1 hour, etc.

FIGURE 1-2
RAINFALL DEPTH-DURATION-FREQUENCY (D-D-F) WORKSHEET
(Continued)

PART E

Tabulate the rainfall Depth-Duration-Frequency statistics below:

Duration	Rainfall depth, in millimeters Frequency, in years						
	2	5	10	25	50	100	500
5-min.							
10-min.*							
15-min.							
30-min.*							
1-hour							
2-hour							
3-hour							
6-hour							
12-hour							
24-hour							

* - Note: 10-min. and 30-min. values are not coded into the PH record.
5" denotes 5 minutes, etc.; 1' denotes 1 hour, etc.

Project No. ______________________ TRACS No. ______________________
Project Name ______________________ Date ______________________
Location/Station ______________________
Designer ______________________ Checker ______________________

FIGURE 1-3
RAINFALL INTENSITY-DURATION-FREQUENCY (I-D-F) WORKSHEET

Divide each rainfall depth from the D-D-F Worksheet (**Figure 1-2 Part E**) by each corresponding duration, in hours, and tabulate below:

Duration	**Rainfall intensity, in millimeters/hour**						
	Frequency, in years						
	2	**5**	**10**	**25**	**50**	**100**	**500**
5-min.							
10-min.							
15-min.							
30-min.							
1-hour							
2-hour							
3-hour							
6-hour							
12-hour							
24-hour							

<u>Note</u>: 5" denotes 5 minutes, etc.; 1′ denotes 1 hour, etc.

RAINFALL DEPTH-DURATION-FREQUENCY (D-D-F) TABLE

Problem:

Develop a Rainfall Depth-Duration-Frequency (D-D-F) table for Bisbee, Arizona.

Solution:

The D-D-F Worksheets (**Figure 1-2, Parts A - E**) are used as follows:

ARIZONA DEPARTMENT OF TRANSPORTATION
HYDROLOGIC DESIGN DATA

Project No. EXAMPLE 1-1 TRACS No. ____
Project Name D-D-F TABLE FOR BISBEE, AZ Date ____
Location/Station ____
Designer ____ Checker ____

EXAMPLE 1-1

RAINFALL DEPTH-DURATION-FREQUENCY (D-D-F) WORKSHEET

PART A

Determine rainfall depths from the isopluvial maps **(Appendix B)**:

	Rainfall depth, in inches	Rainfall depth, in millimeters
2-year, 6-hour	$P_{2,6'}$ = 1.62	$P_{2,6'}$ = 41.1
2-year, 24-hour	$P_{2,24'}$ = 1.99	$P_{2,24'}$ = 50.5
100-year, 6-hour	$P_{100,6'}$ = 3.56	$P_{100,6'}$ = 90.4
100-year, 24-hour	$P_{100,24'}$ = 4.25	$P_{100,24'}$ = 108.0

Note: $P_{T,t}$ in millimeters = (25.4) $P_{T,t}$ in inches

PART B

Compute the following:

2-year, 1-hour	$-0.279 + \frac{.942\ (P_{2,6'})^2}{(P_{2,24'})} = -0.279 + \frac{.942\ (41.1)^2}{(50.5)}$	$P_{2,1'}$ = 31.2
100-year, 1-hour	$12.55 + \frac{.755\ (P_{100,6'})^2}{(P_{100,24'})} = 12.55 + \frac{.755\ (90.4)^2}{(108.0)}$	$P_{100,1'}$ = 69.7
2-year, 2-hour	$.341(P_{2,6'}) + .659(P_{2,1'}) = .341(41.1) + .659(31.2)$	$P_{2,2'}$ = 34.6
2-year, 3-hour	$.569(P_{2,6'}) + .431(P_{2,1'}) = .569(41.1) + .431(31.2)$	$P_{2,3'}$ = 36.8
2-year, 12-hour	$.500(P_{2,6'}) + .500(P_{2,24'}) = .500(41.1) + .500(50.5)$	$P_{2,12'}$ = 45.8
100-year, 2-hour	$.341(P_{100,6'}) + .659(P_{100,1'}) = .341(90.4) + .659(69.7)$	$P_{100,2'}$ = 76.8
100-year, 3-hour	$.569(P_{100,6'}) + .431(P_{100,1'}) = .569(90.4) + .431(69.7)$	$P_{100,3'}$ = 81.5
100-year, 12-hour	$.500(P_{100,6'}) + .500(P_{100,24'}) = .500(90.4) + .500(108.0)$	$P_{100,12'}$ = 99.2

Note: 5" denotes 5 minutes, etc.; 1′ denotes 1 hour, etc.

FIGURE 1-2 Sheet 1 of 4

RAINFALL DEPTH-DURATION-FREQUENCY (D-D-F) WORKSHEET

PART C

Determine the short-duration rainfall zone (**Figure 1-1**):

Zone = 8

Determine the short-duration rainfall ratios (**Table 1-1**):

Duration (minutes)	Ratio	
	2-Year	100-Year
5	A = 0.34	E = 0.30
10	B = 0.51	F = 0.46
15	C = 0.62	G = 0.59
30	D = 0.82	H = 0.80

Compute the following:

2-year, 5-min	(A) $(P_{2,1'})$ = (0.34)(31.2)	$P_{2,5"}$ = 10.6
2-year, 10-min	(B) $(P_{2,1'})$ = (0.51)(31.2)	$P_{2,10"}$ = 15.9
2-year, 15-min	(C) $(P_{2,1'})$ = (0.62)(31.2)	$P_{2,15"}$ = 19.3
2-year, 30-min	(D) $(P_{2,1'})$ = (0.82)(31.2)	$P_{2,30"}$ = 25.6
100-year, 5-min	(E) $(P_{100,1'})$ = (0.30)(69.7)	$P_{100,5"}$ = 20.9
100-year, 10-min	(F) $(P_{100,1'})$ = (0.46)(69.7)	$P_{100,10"}$ = 32.1
100-year, 15-min	(G) $(P_{100,1'})$ = (0.59)(69.7)	$P_{100,15"}$ = 41.1
100-year, 30-min	(H) $(P_{100,1'})$ = (0.80)(69.7)	$P_{100,30"}$ = 55.8

Note: 5" denotes 5 minutes, etc.; 1′ denotes 1 hour, etc.

FIGURE 1-2 Sheet 2 of 4

RAINFALL DEPTH-DURATION-FREQUENCY (D-D-F) WORKSHEET

PART D

For any flood frequency (T-yr) other than 2-year or 100-year, calculate the rainfall depth for each rainfall duration (*t*) by the following equation:

$$P_{T,t} = (X)(P_{2,t}) + (Y)(P_{100,t})$$

where X and Y for a selected frequency (T-yr) are:

Frequency (T-yr)	X	Y
5-year	.674	.278
10-year	.496	.449
25-year	.293	.669
50-year	.146	.835
500-year	-.337	1.381

Selected frequency (T-yr) = 5-year X = 0.674 Y = 0.278

5-min	$(X)(P_{2,5"}) + (Y)(P_{100,5"})$ = (0.674)(10.6) + (0.278)(20.9)	$P_{5,5"}$	= 13.0
10-min	$(X)(P_{2,10"}) + (Y)(P_{100,10"})$ = (0.674)(15.9) + (0.278)(32.1)	$P_{5,10"}$	= 19.6
15-min	$(X)(P_{2,15"}) + (Y)(P_{100,15"})$ = (0.674)(19.3) + (0.278)(41.1)	$P_{5,15"}$	= 24.4
30-min	$(X)(P_{2,30"}) + (Y)(P_{100,30"})$ = (0.674)(25.6) + (0.278)(55.8)	$P_{5,30"}$	= 32.8
1-hour	$(X)(P_{2,1'}) + (Y)(P_{100,1'})$ = (0.674)(31.2) + (0.278)(69.7)	$P_{5,1'}$	= 40.4
2-hour	$(X)(P_{2,2'}) + (Y)(P_{100,2'})$ = (0.674)(34.6) + (0.278)(76.8)	$P_{5,2'}$	= 44.7
3-hour	$(X)(P_{2,3'}) + (Y)(P_{100,3'})$ = (0.674)(36.8) + (0.278)(81.5)	$P_{5,3'}$	= 47.5
6-hour	$(X)(P_{2,6'}) + (Y)(P_{100,6'})$ = (0.674)(41.1) + (0.278)(90.4)	$P_{5,6'}$	= 52.8
12-hour	$(X)(P_{2,12'}) + (Y)(P_{100,12'})$ = (0.674)(45.8) + (0.278)(99.2)	$P_{5,12'}$	= 58.4
24-hour	$(X)(P_{2,24'}) + (Y)(P_{100,24'})$ = (0.674)(50.5) + (0.278)(108.0)	$P_{5,24'}$	= 64.1

Note: 5" denotes 5 minutes, etc.; 1' denotes 1 hour, etc.

FIGURE 1-2 Sheet 3 of 4

RAINFALL DEPTH-DURATION-FREQUENCY (D-D-F) WORKSHEET

PART D

For any flood frequency (T-yr) other than 2-year or 100-year, calculate the rainfall depth for each rainfall duration (*t*) by the following equation:

$$P_{T,t} = (X)(P_{2,t}) + (Y)(P_{100,t})$$

where X and Y for a selected frequency (T-yr) are:

Frequency (T-yr)	X	Y
5-year	.674	.278
10-year	.496	.449
25-year	.293	.669
50-year	.146	.835
500-year	-.337	1.381

Selected frequency (T-yr) = 10-year X = 0.496 Y = 0.449

5-min	$(X)(P_{2,5''}) + (Y)(P_{100,5''})$ = (0.496)(10.6) + (0.449)(20.9)	$P_{10,5''}$	= 14.6
10-min	$(X)(P_{2,10''}) + (Y)(P_{100,10''})$ = (0.496)(15.9) + (0.449)(32.1)	$P_{10,10''}$	= 22.3
15-min	$(X)(P_{2,15''}) + (Y)(P_{100,15''})$ = (0.496)(19.3) + (0.449)(41.1)	$P_{10,15''}$	= 28.0
30-min	$(X)(P_{2,30''}) + (Y)(P_{100,30''})$ = (0.496)(25.6) + (0.449)(55.8)	$P_{10,30''}$	= 37.8
1-hour	$(X)(P_{2,1'}) + (Y)(P_{100,1'})$ = (0.496)(31.2) + (0.449)(69.7)	$P_{10,1'}$	= 46.8
2-hour	$(X)(P_{2,2'}) + (Y)(P_{100,2'})$ = (0.496)(34.6) + (0.449)(76.8)	$P_{10,2'}$	= 51.6
3-hour	$(X)(P_{2,3'}) + (Y)(P_{100,3'})$ = (0.496)(36.8) + (0.449)(81.5)	$P_{10,3'}$	= 54.8
6-hour	$(X)(P_{2,6'}) + (Y)(P_{100,6'})$ = (0.496)(41.1) + (0.449)(90.4)	$P_{10,6'}$	= 61.0
12-hour	$(X)(P_{2,12'}) + (Y)(P_{100,12'})$ = (0.496)(45.8) + (0.449)(99.2)	$P_{10,12'}$	= 67.3
24-hour	$(X)(P_{2,24'}) + (Y)(P_{100,24'})$ = (0.496)(50.5) + (0.449)(108.0)	$P_{10,24'}$	= 73.5

Note: 5" denotes 5 minutes, etc.; 1′ denotes 1 hour, etc.

FIGURE 1-2 Sheet 3 of 4

RAINFALL DEPTH-DURATION-FREQUENCY (D-D-F) WORKSHEET

PART D

For any flood frequency (T-yr) other than 2-year or 100-year, calculate the rainfall depth for each rainfall duration (*t*) by the following equation:

$$P_{T,t} = (X)(P_{2,t}) + (Y)(P_{100,t})$$

where X and Y for a selected frequency (T-yr) are:

Frequency (T-yr)	X	Y
5-year	.674	.278
10-year	.496	.449
25-year	.293	.669
50-year	.146	.835
500-year	-.337	1.381

Selected frequency (T-yr) = 25-year X = 0.293 Y = 0.669

5-min	$(X)(P_{2,5"}) + (Y)(P_{100,5"})$	= (0.293)(10.6) + (0.669)(20.9)	$P_{25,5"}$	= 17.1
10-min	$(X)(P_{2,10"}) + (Y)(P_{100,10"})$	= (0.293)(15.9) + (0.669)(32.1)	$P_{25,10"}$	= 26.1
15-min	$(X)(P_{2,15"}) + (Y)(P_{100,15"})$	= (0.293)(19.3) + (0.669)(41.1)	$P_{25,15"}$	= 33.2
30-min	$(X)(P_{2,30"}) + (Y)(P_{100,30"})$	= (0.293)(25.6) + (0.669)(55.8)	$P_{25,30"}$	= 44.8
1-hour	$(X)(P_{2,1'}) + (Y)(P_{100,1'})$	= (0.293)(31.2) + (0.669)(69.7)	$P_{25,1'}$	= 55.8
2-hour	$(X)(P_{2,2'}) + (Y)(P_{100,2'})$	= (0.293)(34.6) + (0.669)(76.8)	$P_{25,2'}$	= 61.5
3-hour	$(X)(P_{2,3'}) + (Y)(P_{100,3'})$	= (0.293)(36.8) + (0.669)(81.5)	$P_{25,3'}$	= 65.3
6-hour	$(X)(P_{2,6'}) + (Y)(P_{100,6'})$	= (0.293)(41.1) + (0.669)(90.4)	$P_{25,6'}$	= 72.5
12-hour	$(X)(P_{2,12'}) + (Y)(P_{100,12'})$	= (0.293)(45.8) + (0.669)(99.2)	$P_{25,12'}$	= 79.8
24-hour	$(X)(P_{2,24'}) + (Y)(P_{100,24'})$	= (0.293)(50.5) + (0.669)(108.0)	$P_{25,24'}$	= 87.0

Note: 5" denotes 5 minutes, etc.; 1' denotes 1 hour, etc.

FIGURE 1-2 Sheet 3 of 4

RAINFALL DEPTH-DURATION-FREQUENCY (D-D-F) WORKSHEET

PART D

For any flood frequency (T-yr) other than 2-year or 100-year, calculate the rainfall depth for each rainfall duration (*t*) by the following equation:

$$P_{T,t} = (X)(P_{2,t}) + (Y)(P_{100,t})$$

where X and Y for a selected frequency (T-yr) are:

Frequency (T-yr)	X	Y
5-year	.674	.278
10-year	.496	.449
25-year	.293	.669
50-year	.146	.835
500-year	-.337	1.381

Selected frequency (T-yr) = 50-year X = 0.146 Y = 0.835

5-min	$(X)(P_{2,5"}) + (Y)(P_{100,5"})$	= (0.146)(10.6) + (0.835)(20.9)	$P_{50,5"}$ = 19.0
10-min	$(X)(P_{2,10"}) + (Y)(P_{100,10"})$	= (0.146)(15.9) + (0.835)(32.1)	$P_{50,10"}$ = 29.1
15-min	$(X)(P_{2,15"}) + (Y)(P_{100,15"})$	= (0.146)(19.3) + (0.835)(41.1)	$P_{50,15"}$ = 37.1
30-min	$(X)(P_{2,30"}) + (Y)(P_{100,30"})$	= (0.146)(25.6) + (0.835)(55.8)	$P_{50,30"}$ = 50.3
1-hour	$(X)(P_{2,1'}) + (Y)(P_{100,1'})$	= (0.146)(31.2) + (0.835)(69.7)	$P_{50,1'}$ = 62.8
2-hour	$(X)(P_{2,2'}) + (Y)(P_{100,2'})$	= (0.146)(34.6) + (0.835)(76.8)	$P_{50,2'}$ = 69.2
3-hour	$(X)(P_{2,3'}) + (Y)(P_{100,3'})$	= (0.146)(36.8) + (0.835)(81.5)	$P_{50,3'}$ = 73.4
6-hour	$(X)(P_{2,6'}) + (Y)(P_{100,6'})$	= (0.146)(41.1) + (0.835)(90.4)	$P_{50,6'}$ = 81.5
12-hour	$(X)(P_{2,12'}) + (Y)(P_{100,12'})$	= (0.146)(45.8) + (0.835)(99.2)	$P_{50,12'}$ = 89.5
24-hour	$(X)(P_{2,24'}) + (Y)(P_{100,24'})$	= (0.146)(50.5) + (0.835)(108.0)	$P_{50,24'}$ = 97.6

Note: 5" denotes 5 minutes, etc.; 1' denotes 1 hour, etc.

FIGURE 1-2 Sheet 3 of 4

RAINFALL DEPTH-DURATION-FREQUENCY (D-D-F) WORKSHEET

PART D

For any flood frequency (T-yr) other than 2-year or 100-year, calculate the rainfall depth for each rainfall duration (*t*) by the following equation:

$$P_{T,t} = (X)(P_{2,t}) + (Y)(P_{100,t})$$

where X and Y for a selected frequency (T-yr) are:

Frequency (T-yr)	X	Y
5-year	.674	.278
10-year	.496	.449
25-year	.293	.669
50-year	.146	.835
500-year	-.337	1.381

Selected frequency (T-yr) = 500-year X = -0.337 Y = 1.381

5-min	$(X)(P_{2,5"}) + (Y)(P_{100,5"})$ = (-0.337)(10.6) + (1.381)(20.9)	$P_{500,5"}$	= 25.3
10-min	$(X)(P_{2,10"}) + (Y)(P_{100,10"})$ = (-0.337)(15.9) + (1.381)(32.1)	$P_{500,10"}$	= 39.0
15-min	$(X)(P_{2,15"}) + (Y)(P_{100,15"})$ = (-0.337)(19.3) + (1.381)(41.1)	$P_{500,15"}$	= 50.3
30-min	$(X)(P_{2,30"}) + (Y)(P_{100,30"})$ = (-0.337)(25.6) + (1.381)(55.8)	$P_{500,30"}$	= 68.4
1-hour	$(X)(P_{2,1'}) + (Y)(P_{100,1'})$ = (-0.337)(31.2) + (1.381)(69.7)	$P_{500,1'}$	= 85.7
2-hour	$(X)(P_{2,2'}) + (Y)(P_{100,2'})$ = (-0.337)(34.6) + (1.381)(76.8)	$P_{500,2'}$	= 94.4
3-hour	$(X)(P_{2,3'}) + (Y)(P_{100,3'})$ = (-0.337)(36.8) + (1.381)(81.5)	$P_{500,3'}$	= 100.1
6-hour	$(X)(P_{2,6'}) + (Y)(P_{100,6'})$ = (-0.337)(41.1) + (1.381)(90.4)	$P_{500,6'}$	= 111.0
12-hour	$(X)(P_{2,12'}) + (Y)(P_{100,12'})$ = (-0.337)(45.8) + (1.381)(99.2)	$P_{500,12'}$	= 121.6
24-hour	$(X)(P_{2,24'}) + (Y)(P_{100,24'})$ = (-0.337)(50.5) + (1.381)(108.0)	$P_{500,24'}$	= 132.1

Note: 5" denotes 5 minutes, etc.; 1′ denotes 1 hour, etc.

FIGURE 1-2 Sheet 3 of 4

RAINFALL DEPTH-DURATION-FREQUENCY (D-D-F) WORKSHEET

PART E

Tabulate the rainfall Depth-Duration-Frequency statistics below:

Duration	Rainfall depth, in millimeters — Frequency, In years						
	2	5	10	25	50	100	500
5-min.	10.6	13.0	14.6	17.1	19.0	20.9	25.3
10-min.*	15.9	19.6	22.3	26.1	29.1	32.1	39.0
15-min.	19.3	24.4	28.0	33.2	37.1	41.1	50.3
30-min.*	25.6	32.8	37.8	44.8	50.3	55.8	68.4
1-hour	31.2	40.4	46.8	55.8	62.8	69.7	85.7
2-hour	34.6	44.7	51.6	61.5	69.2	76.8	94.4
3-hour	36.8	47.5	54.8	65.3	73.4	81.5	100.1
6-hour	41.1	52.8	61.0	72.5	81.5	90.4	111.0
12-hour	45.8	58.4	67.3	79.8	89.5	99.2	121.6
24-hour	50.5	64.1	73.5	87.0	97.6	108.0	132.1

* - Note: 10-min. and 30-min. values are not coded into the PH record.
5" denotes 5 minutes, etc.; 1' denotes 1 hour, etc.

FIGURE 1-2 Sheet 4 of 4

EXAMPLE 1-2
PH RECORD CODING

Problem:

Code a PH record for a watershed at Bisbee, Arizona for various flood frequencies and watershed sizes.

Solution:

The D-D-F table of the required rainfall depth-duration-frequency (D-D-F) statistics is first prepared (See **Example 1-1**).

a. For a 100-yr, 6-hr flood and 2.0 square kilometer watershed:

Field

	1	2	3	4	5	6	7	8	9	10
PH		1.94	20.9	41.1	69.7	76.8	81.5	90.4		

b. For a 5-yr, 6-hr flood and 2.0 square kilometer watershed:

Field

	1	2	3	4	5	6	7	8	9	10
PH	20	1.94	13.0	24.4	40.4	44.7	47.5	52.8		

c. For a 50-yr, 6-hr flood and a 47 square kilometer watershed:

Field

	1	2	3	4	5	6	7	8	9	10
PH		47	19.0	37.1	62.8	69.2	73.4	81.5	89.5	97.6

EXAMPLE 1-3
RAINFALL INTENSITY-DURATION-FREQUENCY (I-D-F) TABLE

Problem:

Develop a site-specific Intensity-Duration-Frequency (I-D-F) graph for Bisbee, Arizona.

Solution:

The D-D-F table is first produced (See **Example 1-1**). Then the I-D-F Worksheet (**Figure 1-4**) is used. The rainfall intensities, in inches per hour, are plotted against corresponding rainfall durations, in hours, on log-log paper.

ARIZONA DEPARTMENT OF TRANSPORTATION
HYDROLOGIC DESIGN DATA

Project No. EXAMPLE 1-3 TRACS No. ____
Project Name I-D-F GRAPH Date ____
Location/Station BISBEE, ARIZONA
Designer ____ Checker ____

EXAMPLE 1-3

RAINFALL INTENSITY-DURATION-FREQUENCY (I-D-F) WORKSHEET

Divide each rainfall depth from the D-D-F Worksheet **(Figure 1-3 - Part E)**, by each corresponding duration, in hours, and tabulate below:

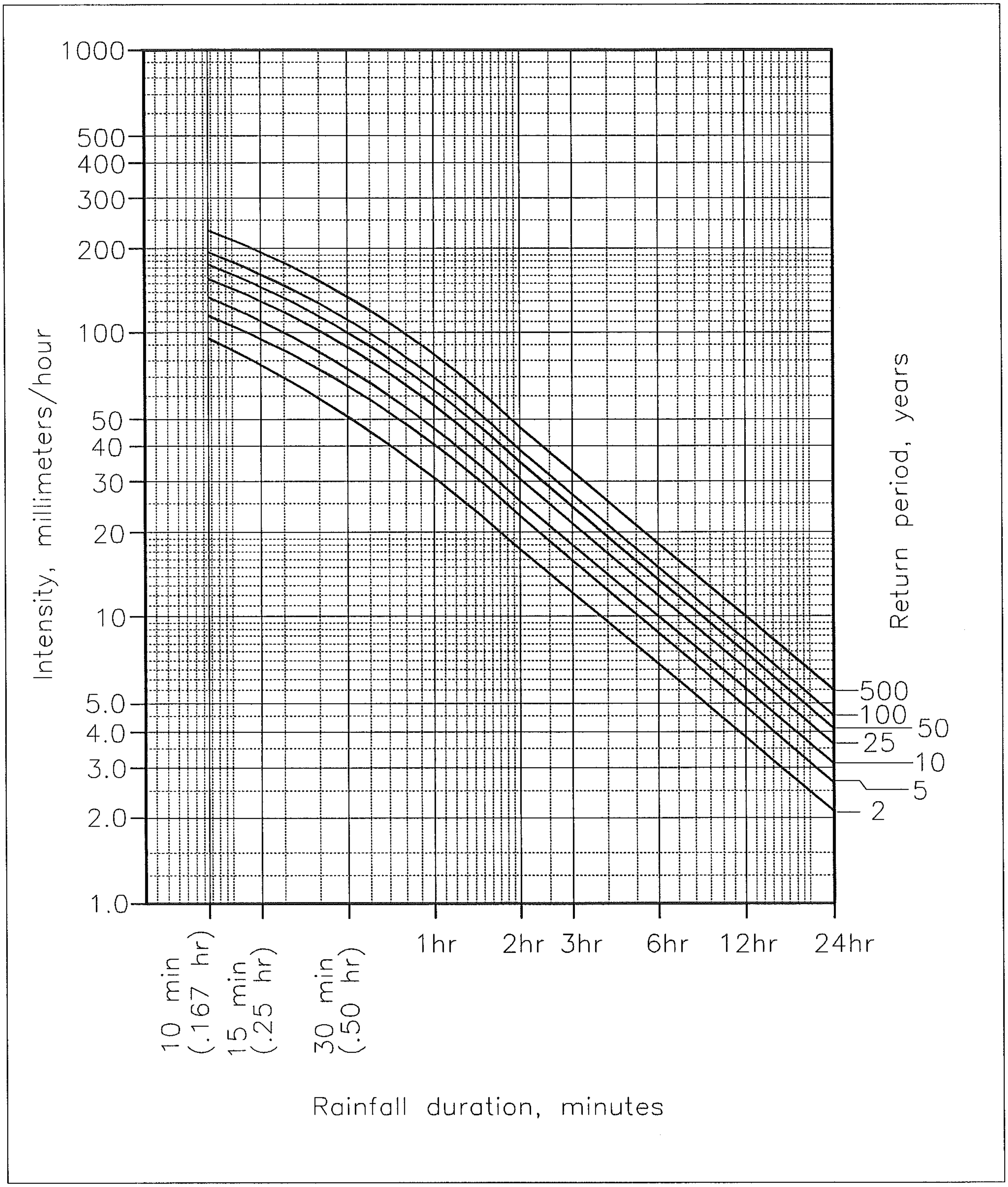
Duration	Rainfall intensity, in millimeters/hour Frequency, in years						
	2	5	10	25	50	100	500
5-min.	127.2	156.0	175.2	205.2	228.0	250.8	303.6
10-min.	95.4	117.6	133.8	156.6	174.6	192.6	234.0
15-min.	77.2	97.6	112.0	132.8	148.4	164.4	201.2
30-min.	51.2	65.6	75.6	89.6	100.6	111.6	136.8
1-hour	31.2	40.4	46.8	55.8	62.8	69.7	85.7
2-hour	17.3	22.4	25.8	30.8	34.6	38.4	47.2
3-hour	12.3	15.8	18.3	21.8	24.5	27.2	33.4
6-hour	6.9	8.8	10.2	12.1	13.6	15.1	18.5
12-hour	3.8	4.9	5.6	6.7	7.5	8.3	10.1
24-hour	2.1	2.7	3.1	3.6	4.1	4.5	5.5

* - Note: 10-min. and 30-min. values are not coded into the PH record.
5" denotes 5 minutes, etc.; 1' denotes 1 hour, etc.

FIGURE 1-3

EXAMPLE 1-3

RAINFALL INTENSITY-DURATION-FREQUENCY
SITE SPECIFIC I-D-F GRAPH FOR BISBEE, ARIZONA



CHAPTER 2
RATIONAL METHOD

2.1 INTRODUCTION

The Rational Method relates rainfall intensity, a runoff coefficient and a drainage area size to the direct runoff from the drainage basin.

Three basic assumptions of the Rational Method are:

a. The frequency of the storm runoff is the same as the frequency of the rainfall producing the runoff (i.e., a 25-year runoff event results from a 25-year rainfall event).

b. The peak runoff occurs when all parts of the drainage basin are contributing to the runoff.

c. Rainfall is uniform over the watershed.

2.1.1 General Discussion

The Rational Method, as presented herein, can be used to estimate peak discharges, the runoff hydrograph shape, and runoff volume for small, uniform drainage areas that are not larger than 65 hectares (160 acres) in size. The method is usually used to size drainage structures for the peak discharge of a selected return period. An extension of the basic method is provided to estimate the shape of the runoff hydrograph if it is necessary to design retention/detention facilities and/or to design drainage facilities that will require routing of the runoff hydrograph through the structure.

The Rational Method is based on the equation: $Q = C\,i\,A / 363$ (2-1)

where

- Q = the peak discharge, in m^3/s, of selected return period,
- C = the runoff coefficient,
- i = the average rainfall intensity, in millimeters/hr, of calculated rainfall duration for the selected rainfall return period, and
- A = the contributing drainage area, in hectares.

2.2 PROCEDURE

2.2.1 General Considerations

1. Depending on the intended application, the runoff coefficient (C) should be selected based on the character of the existing land surface or the projected character of the land surface under future development conditions. In some situations, it may be necessary to estimate C for both existing and future conditions.

2. Land-use must be carefully considered because the evaluation of land-use will affect both the estimation of C and also the estimation of the watershed time of concentration (T_c).

3. The peak discharge (Q) is generally quite sensitive to the calculation of T_c and care must be exercised in obtaining the most appropriate estimate of T_c.

4. Both C and the rainfall intensity (i) will vary if peak discharges for different flood return periods are desired.

5. Since the T_c equation is a function of rainfall intensity (i), T_c will also vary for different flood return periods.

2.2.2 Applications and Limitations

1. The total drainage area must be less than or equal to 65 hectares (160 acres).

2. T_c shall not exceed 60 minutes.

3. The land-use of the contributing area must be fairly consistent over the entire area; that is, the area should not consist of a large percentage of two or more land-uses, such as 50 percent commercial and 50 percent undeveloped. This will lead to inconsistent estimates of T_c (and therefore i) and errors in selecting the most appropriate C coefficient.

4. The contributing drainage area cannot have drainage structures or other facilities in the area that would require flood routing to correctly estimate the discharge at the point of interest.

5. Drainage areas that do not meet the above conditions will require the use of an appropriate rainfall-runoff model (the HEC-1 Program) to estimate flood discharges.

2.2.3 Estimation of Area (A)

An adequate topographic map of the drainage area and surrounding land is needed to define the drainage boundary and to estimate the area (A), in hectares. The map should be supplemented with aerial photographs, if available, especially if the area is developed. If the area is presently undeveloped but is to undergo development, then the land development plan and maps should be obtained because these may indicate a change in the drainage boundary due to road construction or land grade changes. If development plans are not available, then land-use should be based on current zoning of the area.

The delineation of the drainage boundary needs to be carefully determined. The contributing drainage area for a lower intensity storm does not always coincide with the drainage area for more intense storms. This is particularly true for urban areas where roads can form a drainage boundary for small storms but more intense storm runoff can cross roadway crowns, curbs, etc. resulting in a larger contributing area. Floods on alluvial fans (active and inactive) and in distributary flow systems can result in increased contributing drainage areas during larger and more intense storms. It is generally prudent to consider the largest reasonable drainage area in such situations.

2.2.4 Estimation of Rainfall Intensity (i)

The intensity (i) in Equation 2-1 is the average rainfall intensity in millimeters/hour for the period of maximum rainfall of a specified return period (frequency) having a duration equal to the time of concentration (T_C) for the drainage area. The frequency is usually specified according to a design criteria or standard for the intended application. The rainfall intensity (i) is obtained from an intensity-duration-frequency (I-D-F) graph. Two methods can be used for obtaining I-D-F information: 1) two generalized I-D-F graphs are provided that can be used for any site in Arizona, and 2) a site-specific I-D-F graph can be developed, if desired. The two generalized I-D-F graphs are shown in **Figure 2-1** for Zone 6, and **Figure 2-2** for Zone 8, respectively. The delineation of the two rainfall zones for Arizona is shown in **Figure 1-1** of Chapter 1 - Rainfall. Procedures for developing a site-specific I-D-F graph are described in Chapter 1.

The intensity (i) in Equation 2-1 is the average rainfall intensity for rainfall of a selected return period from an I-D-F graph for a rainfall duration that is equal to the time of concentration (T_c) as calculated according to the procedure described below. A minimum rainfall duration of 10 minutes is to be used if the calculated T_c is <u>less</u> than 10 minutes. The Rational Method should not be used if the calculated T_c is greater than 60 minutes.

2.2.5 Estimation of Time of Concentration (T_c)

Time of concentration (T_c) is to be calculated by Equation 2-2:

$$T_C = 18.3\ L^{0.5}\ K_b^{0.52}\ S^{-0.31}\ i^{-0.38} \qquad (2\text{-}2)$$

Note: Reference Papadakis and Kazan, 1987.

where

- T_c = the time of concentration, in hours,
- L = the length of the longest flow path, in kilometers,
- K_b = the watershed resistance coefficient,
- S = the slope of the longest flow path, in meters/kilometer, and
- i = the average rainfall intensity, in millimeters/hr, for a duration of rainfall equal to T_c (the same (i) as Equation 2-1) unless T_c is less than 10 minutes, in which case the (i) of Equation 2-1 is for a 10-minute duration).

The longest flow path will be estimated from the best available map and the length (L) measured from the map.

FIGURE 2-1
GENERALIZED I-D-F GRAPH FOR ZONE 6 OF ARIZONA

Example: For a selected 10-year return period, P_1 = 50 millimeters. T_c is calculated as 20 minutes. Therefore, (i) = 106 mm/hr.

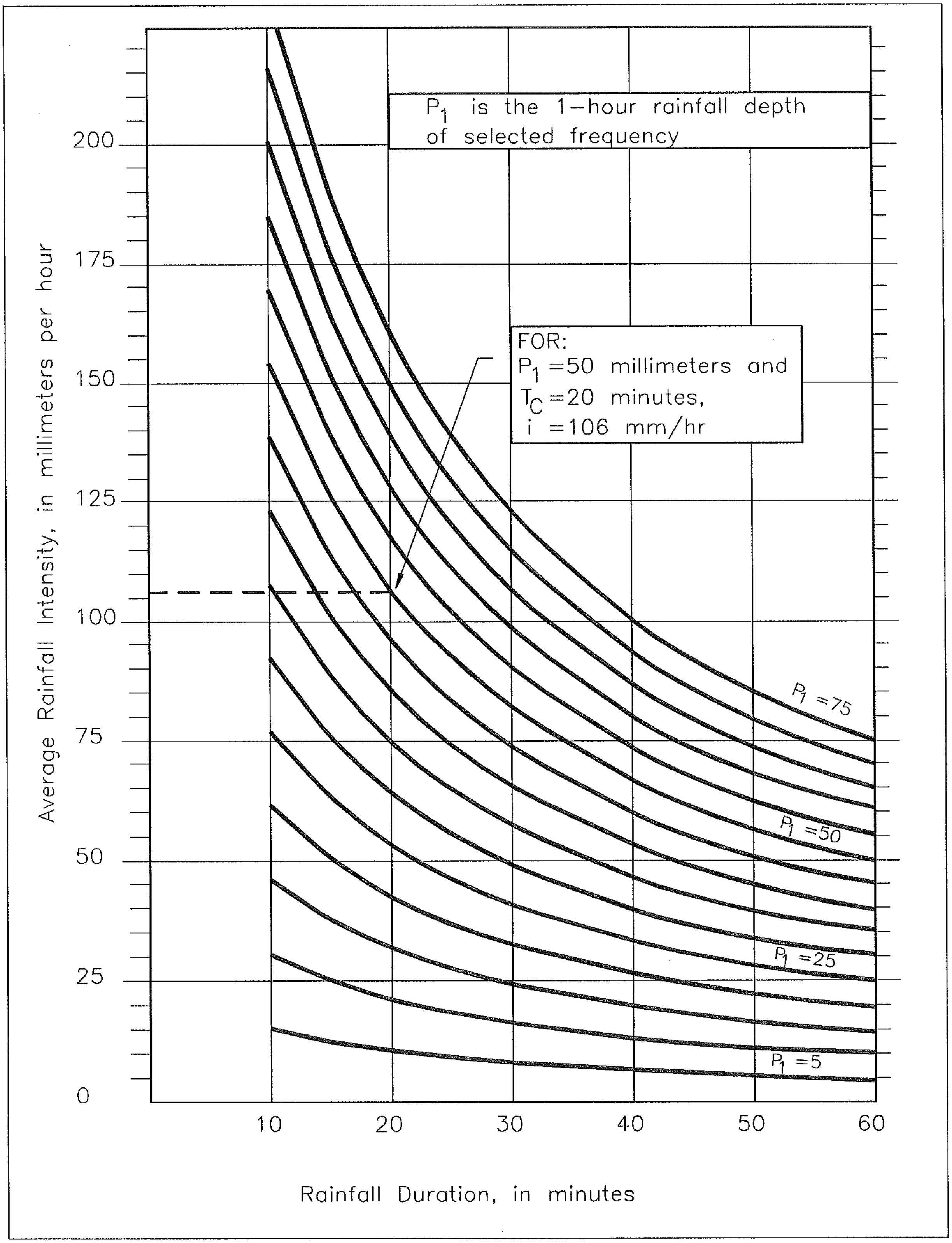
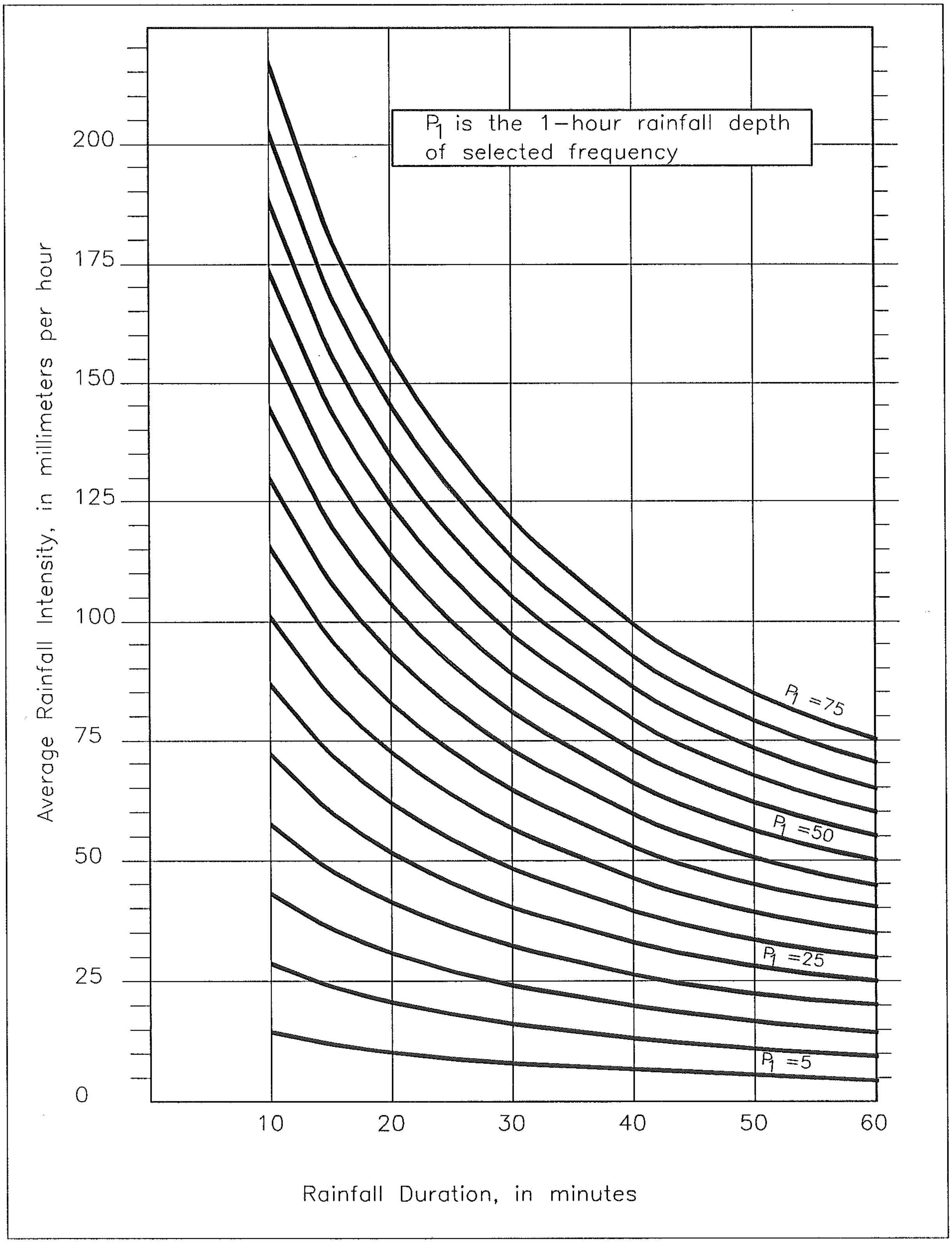


FIGURE 2-2
GENERALIZED I-D-F GRAPH FOR ZONE 8 OF ARIZONA



The slope (S), in meters/kilometer, will be calculated by one of two methods:

1. If the longest flow path has a uniform gradient with no appreciable grade breaks, then the slope is calculated by Equation 2-3;

$$S = \frac{H}{L} \tag{2-3}$$

where H = the change in elevation, in meters, along L, and
L = as defined in Equation 2-2.

2. If the longest flow path does not have a uniform gradient or has distinct grade breaks, then the slope is calculated by Equation 2-4:

$$S = 1,000 \left(\frac{d}{j}\right)^2 \tag{2-4}$$

where
$$d = 1,000 \times L$$

$$j = \sum \left(\frac{d_i{}^3}{H_i}\right)^{1/2}$$

Note: Reference, Pima County Department of Transportation and Flood Control District, September 1979.

and d_i = an incremental change in length, in meters, along the longest flowpath and
H_i = an incremental change in elevation, in meters, for each length segment, d_i .

The resistance coefficient (K_b) is selected from **Table 2-1**. Use of **Table 2-1** requires a classification as to the landform and a determination of the nature of runoff; whether in a defined drainage network of rills, gullies, channels, etc., or predominantly as overland flow.

TABLE 2-1
RESISTANCE COEFFICIENT (K_b) FOR USE WITH THE RATIONAL METHOD T_c EQUATION

DESCRIPTION OF LANDFORM	K_b	
	Defined Drainage Network	Overland Flow Only
Mountain, with forest and dense ground cover (overland slopes - 50% or greater)	0.15	0.30
Mountain, with rough rock and boulder cover (overland slopes - 50% or greater)	0.12	0.25
Foothills (overland slopes - 10% to 50%)	0.10	0.20
Alluvial fans, Pediments and Rangeland (overland slopes - 10% or less)	0.05	0.10
Irrigated Pasture [a]	----	0.20
Tilled Agricultural Fields [a]	----	0.08
Urban		
Residential, L is less than 300 meters [b]	0.04	----
Residential, L is greater than 300 meters [b]	0.025	----
Grass; parks, cemeteries, etc. [a]	----	0.20
Bare ground; playgrounds, etc. [a]	----	0.08
Paved; parking lots, etc. [a]	----	0.02

Notes: a - No defined drainage network.
b - L is length in the T_c equation. Streets serve as drainage network.

The solution of Equation 2-2 is an iterative process since the determination of (i) requires the knowledge of the value of T_c. Therefore, Equation 2-2 will be solved by a trial-and-error procedure. After L, K_b, and S are estimated and after the appropriate I-D-F graph is selected or prepared, a value for T_c will be estimated (a trial value) and (i) will be read from the I-D-F graph for the corresponding value of duration = T_c. That (i) will be used in Equation 2-2 and T_c will be calculated. If the calculated value of T_c does not equal the trial value of T_c, then the process is repeated until the calculated and trial values of T_c are acceptably close (a difference of less than 10 percent should be acceptable).

2.2.6 Selection of Runoff Coefficient (C)

The runoff coefficient (C) is selected from **Figure 2-3** through **Figure 2-8** depending on the classification of the nature of the watershed. **Figure 2-3** is the C graph to be used for urbanized (developed) watersheds. Select the appropriate curve in **Figure 2-3** based on an estimate of the percent of effective impervious area in the watershed. Effective impervious area is that area that will drain directly to the outlet without flowing over pervious area. (Refer to Chapter 3 - Rainfall Losses, 3.1.1 and Table 3-3, for discussion of effective impervious areas.) **Figure 2-4** through **Figure 2-8** are to be used for undeveloped (natural) watersheds in Arizona, and the C graphs are shown as functions of Hydrologic Soil Group (HSG) and percent vegetation cover. The Hydrologic Soil Group is used to classify soil according to its infiltration rate. The Hydrologic Soil Groups, as defined by USDA, Soil Conservation Service (SCS), 1972 are:

HSG	Definition
A	Soils having high infiltration rates even when thoroughly wetted and consisting chiefly of deep, well to excessively drained sands and gravels. These soils have a high rate of water transmission.
B	Soils having moderate infiltration rates when thoroughly wetted and consisting chiefly of moderately deep to deep, moderately well to well drained soils with moderately fine to moderately coarse textures. These soils have a moderate rate of water transmission.

HSG	Definition
C	Soils having slow infiltration rates when thoroughly wetted and consisting chiefly of soils with a layer that impedes downward movement of water, or soils with moderately fine to fine texture. These soils have a slow rate of water transmission.
D	Soils having very slow infiltration rates when thoroughly wetted and consisting chiefly of clay soils with a high swelling potential, soils with a permanent high water table, soils with a claypan at or near the surface, and shallow soils over nearly impervious material. These soils have a very slow rate of water transmission.

The percent vegetation cover is the percent of land surface that is covered by vegetation. Vegetation cover is evaluated on plant basal area for grasses and forbs, and on canopy cover for trees and shrubs (see Appendix C).

Information on Hydrologic Soil Group and percent vegetation cover can usually be obtained from the detailed soil surveys that are prepared by the SCS. When detailed soil surveys are not available for the watershed, then the general soil maps and accompanying reports by the SCS for each county in Arizona are to be used. A site visit is encouraged to confirm watershed and soil conditions.

It may be required to select the appropriate C value for existing conditions and another C value for anticipated future conditions, if the watershed is undergoing development. Estimation of peak discharges for various conditions of development in the drainage area or for different periods will also require separate estimates of T_c for each existing or assumed land-use condition and for each flood return period.

2.2.7 Estimation of Hydrograph Shape

This procedure is to be used where routing of the storm inflow through the drainage structure is desired, such as for the design of a detention basin or pump station. The procedure is based on synthesizing a hydrograph from the peak discharge estimated by the Rational Method and by the use of some dimensionless hydrograph shapes from TR-55 (Soil Conservation Service, 1986). Two sets of dimensionless hydrographs are provided; one set is for use with urbanized watersheds (**Table 2-2**), and the other set is for use with undeveloped watersheds (**Table 2-3**, Both sets of dimensionless unit hydrographs are functions of T_c.

TABLE 2-2
URBAN WATERSHED - COORDINATES (q_t) OF DIMENSIONLESS HYDROGRAPH TO BE USED WITH THE RATIONAL METHOD

Time[a]	q_t values									
	T_c, in hours									
hours	0.17	.18 - .25	.26 - .35	.36 - .45	.46 - .62	.63 - .88	.89 - 1.12	1.13 - 1.38	1.39 - 1.75	1.76 - 2.5
0.0	0	0	0	0	0	0	0	0	0	0
1.0	24	23	20	18	17	13	11	10	9	7
1.3	34	31	28	25	23	18	15	13	11	9
1.6	53	47	41	36	32	24	20	18	15	12
1.9	334	209	118	77	57	36	29	25	21	16
2.0	647	403	235	141	94	46	35	29	25	18
2.1	$\underline{1010}$	739	447	271	170	68	47	38	31	21
2.2	623	$\underline{800}$	676	468	308	115	72	54	41	27
2.3	217	481	$\underline{676}$	$\underline{592}$	467	194	112	81	58	36
2.4	147	250	459	574	$\underline{529}$	294	168	118	82	49
2.5	123	166	283	431	507	380	231	163	112	64
2.6	104	128	196	298	402	$\underline{424}$	289	213	147	82
2.7	86	102	146	216	297	410	329	256	184	104
2.8	76	86	114	163	226	369	$\underline{357}$	284	216	127
3.0	66	70	80	104	140	252	313	$\underline{311}$	255	171
3.2	57	61	66	77	96	172	239	266	$\underline{275}$	201
3.4	51	54	57	63	74	123	175	212	236	$\underline{226}$
3.6	46	49	51	55	61	93	133	163	198	205
3.8	42	44	46	49	53	74	103	129	159	193
4.0	38	40	42	44	47	61	83	104	129	171
4.3	34	35	37	38	41	49	63	78	98	132
4.6	32	33	33	34	36	41	50	61	76	105
5.0	29	30	31	31	32	35	40	47	57	79
5.5	26	27	28	28	29	31	33	37	43	58
6.0	23	24	24	25	26	27	29	31	35	45
6.5	21	21	22	22	23	24	26	27	30	36
7.0	20	20	20	21	21	22	23	24	25	30
7.5	19	19	19	20	20	20	21	22	23	26
8.0	18	18	18	18	19	19	20	20	21	23
9.0	15	16	16	16	16	17	17	18	18	20
10.0	13	13	13	14	14	15	15	16	16	17
12.0	12	12	12	12	12	12	12	12	12	13
16.0	0	0	0	0	0	0	0	1	1	3

Reference: TR-55 (1986), Exhibit 5-II for IA/P = 0.10 and Travel Time = 0.0

Notes:

[a] - Time is the TR-55 hydrograph time minus 10 hours.

[b] - The maximum unit peak discharge, q_{tmax}, is underlined for each hydrograph.

TABLE 2-3
UNDEVELOPED WATERSHED - COORDINATES (q_t) OF DIMENSIONLESS HYDROGRAPH TO BE USED WITH THE RATIONAL METHOD

Time[a]	q_t values									
	T_c, in hours									
hours	0.17	.18 - .25	.26 - .35	.36 - .45	.46 - .62	.63 - .88	.89 - 1.12	1.13 - 1.38	1.39 - 1.75	1.76 - 2.5
0.0	0	0	0	0	0	0	0	0	0	0
1.0	0	0	0	0	0	0	0	0	0	0
1.3	0	0	0	0	0	0	0	0	0	0
1.6	0	0	0	0	0	0	0	0	0	0
1.9	0	0	0	0	0	0	0	0	0	0
2.0	70	7	1	0	0	0	0	0	0	0
2.1	**539**	98	25	7	2	0	0	0	0	0
2.2	377	**371**	151	59	26	2	1	1	0	0
2.3	196	322	**299**	168	89	16	7	5	3	1
2.4	171	221	277	245	170	45	21	13	8	4
2.5	154	182	219	**257**	217	92	42	26	16	8
2.6	134	158	187	213	**229**	137	71	44	27	13
2.7	117	137	162	186	200	166	101	68	42	20
2.8	108	120	141	163	179	**185**	126	91	59	28
3.0	99	104	113	128	144	170	**160**	125	92	51
3.2	89	94	100	109	119	146	154	142	116	73
3.4	83	86	90	96	104	125	138	**142**	128	92
3.6	77	80	84	88	93	110	123	128	**130**	104
3.8	72	74	73	81	85	98	110	117	121	111
4.0	67	69	72	75	78	89	100	107	112	**112**
4.3	61	62	65	67	70	79	87	94	100	106
4.6	59	60	61	62	64	70	77	83	90	97
5.0	56	57	58	58	59	63	67	72	78	86
5.5	51	52	53	54	55	58	60	63	67	75
6.0	46	47	48	50	51	53	55	57	60	66
6.5	43	44	44	45	46	48	50	52	55	60
7.0	42	42	42	43	43	44	46	47	50	54
7.5	40	40	41	41	41	42	43	44	46	49
8.0	38	39	39	39	40	41	41	42	43	46
9.0	34	35	35	35	36	37	38	38	39	40
10.0	30	30	31	31	32	33	34	34	35	37
12.0	28	28	28	28	28	28	28	28	29	30
16.0	0	0	0	0	0	0	1	2	4	7

Reference: TR-55 (1986), Exhibit 5-II for IA/P = 0.50 and Travel Time = 0.0

Notes:

[a] - Time is the TR-55 hydrograph time minus 10 hours.

[b] - The maximum unit peak discharge, q_{tmax}, is underlined for each hydrograph.

2.3 INSTRUCTIONS

A. For estimating peak discharge:

1. Determine the size of the contributing drainage area (A), in hectares.

2. Decide whether the generalized I-D-F graphs will be used or whether a site-specific I-D-F graph will be developed.

   a. If the generalized I-D-F graphs are to be used, determine the Zone from **Figure 1-1** of Chapter 1 - Rainfall. Use the I-D-F graph of **Figure 2-1** if the watershed is in Zone 6, and use **Figure 2-2** if the watershed is in Zone 8.

   b. If a site-specific I-D-F graph is to be used, develop the I-D-F graph by procedures in Chapter 1 - Rainfall.

3. Select the desired return period(s).

4. Determine the 1-hour rainfall depth (P_1) for each return period.
   Note: P_1 = 1-hr rainfall intensity times 1 hour.

5. Estimate the time of concentration (T_c), for each return period, by Equation 2-2.

6. Select the rainfall intensity (i) from the I-D-F graph at a duration equal to T_c which is the value of (i) used in the solution of Equation 2-2 (but not less than 10 minutes).

7. Estimate C:
   a. If the watershed is developed, use **Figure 2-3**. This will require an appraisal of development type and percent effective impervious area. C is selected as a function of P_1 and type of development.

b. If the watershed is undeveloped, use **Figures 2-4** through **2-8**. This will require an appraisal of Hydrologic Soil Group (HSG), A through D, from Soil Conservation Service (SCS) soils reports, and an estimate of percent vegetation cover. C is selected as a function of P_1, and HSG-percent vegetation cover.

8. Calculate the peak discharge by Equation 2-1.

B. For estimating a runoff hydrograph:

1. Calculate Q according to the above instructions.

2. Select the appropriate dimensionless hydrograph coordinates to use from **Table 2-2** or **Table 2-3**. The selection is based on T_c (round to the nearest T_c value in the tables) and on whether the drainage area is urbanized or undeveloped.

3. Read the maximum unit peak discharge, q_{tmax}, for the selected dimensionless hydrograph and computed T_c value in either **Table 2-2** or **Table 2-3.**

4. Calculate: $K = Q/q_{tmax}$.

5. Tabulate the time and q_t values from either **Table 2-2** or **Table 2-3** and multiply each q_t by K.

$$q = Kq_t$$

6. Plot the hydrograph discharge (q) versus time.

7. Draw a smooth hydrograph. This may require extending the rising limb of the hydrograph to intersect the 0 discharge axis.

FIGURE 2-3
RATIONAL "C" COEFFICIENT
DEVELOPED WATERSHEDS

AS A FUNCTION OF RAINFALL DEPTH AND TYPE OF DEVELOPMENT

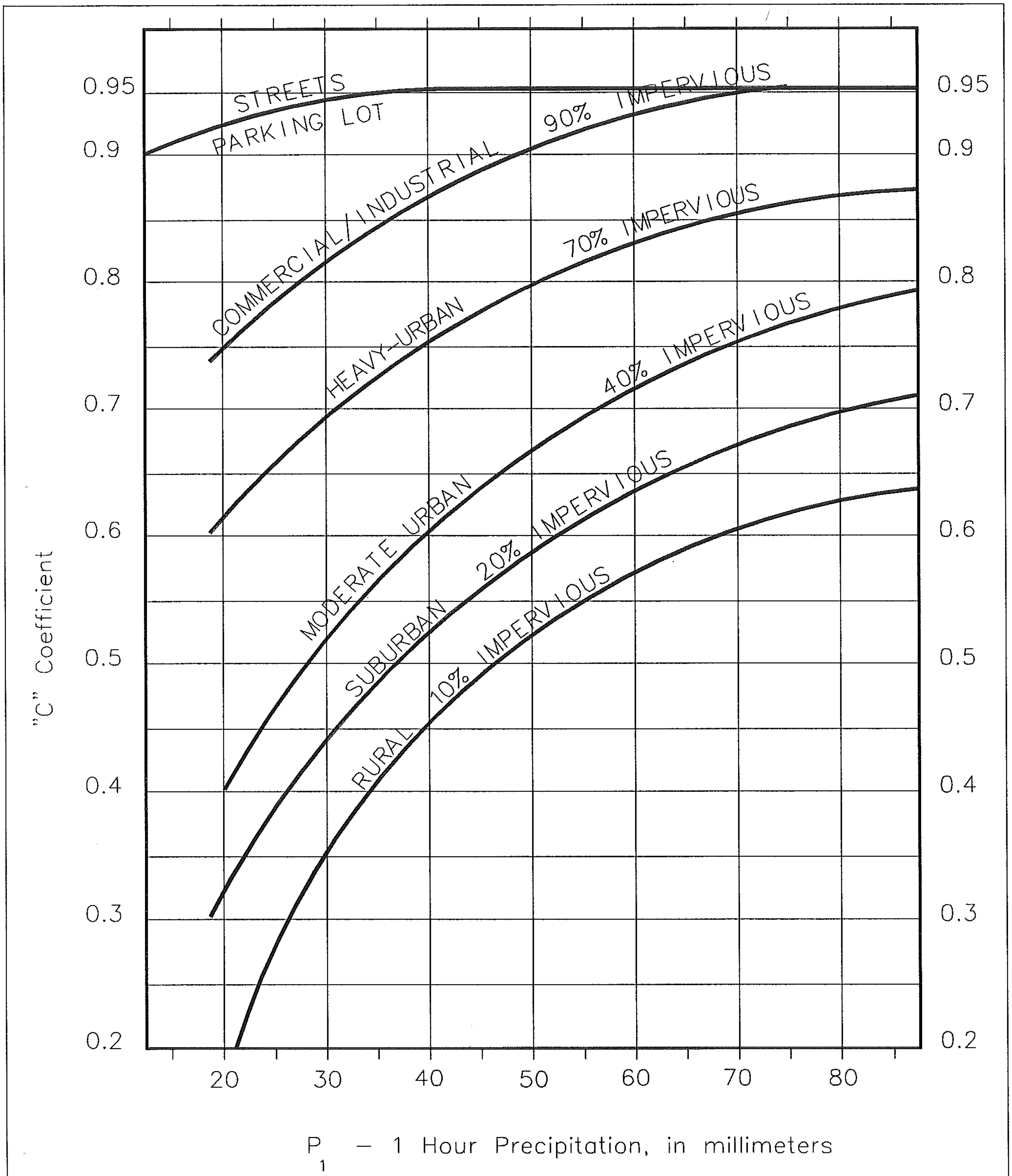


FIGURE 2-4
RATIONAL "C" COEFFICIENT
DESERT
(CACTUS, GRASS & BRUSH)

AS A FUNCTION OF RAINFALL DEPTH, HYDROLOGIC SOIL GROUP (HSG), AND % OF VEGETATION COVER.

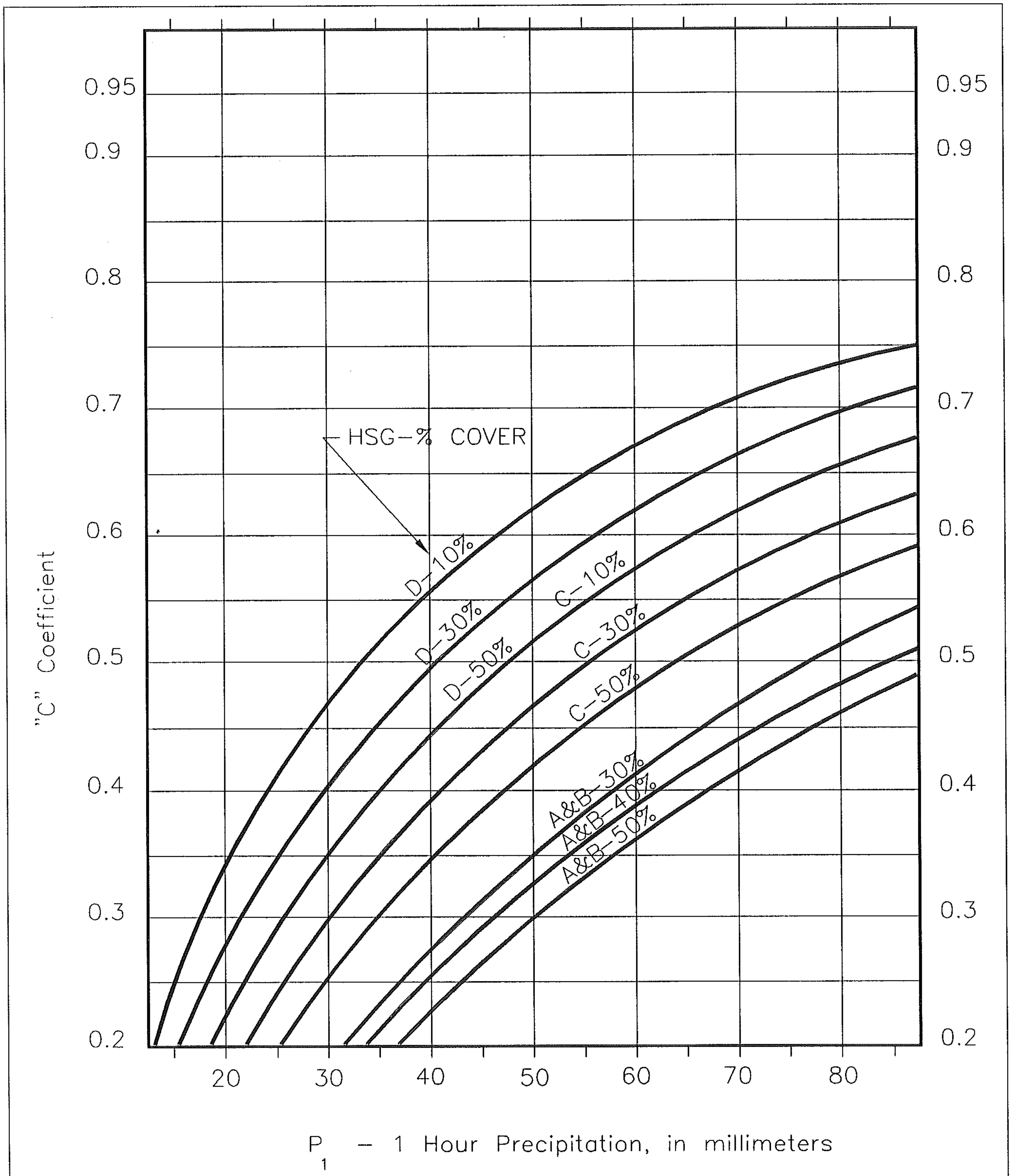


FIGURE 2-5
RATIONAL "C" COEFFICIENT
UPLAND RANGELAND
(GRASS & BRUSH)

AS A FUNCTION OF RAINFALL DEPTH, HYDROLOGIC SOIL GROUP (HSG), AND % OF VEGETATION COVER

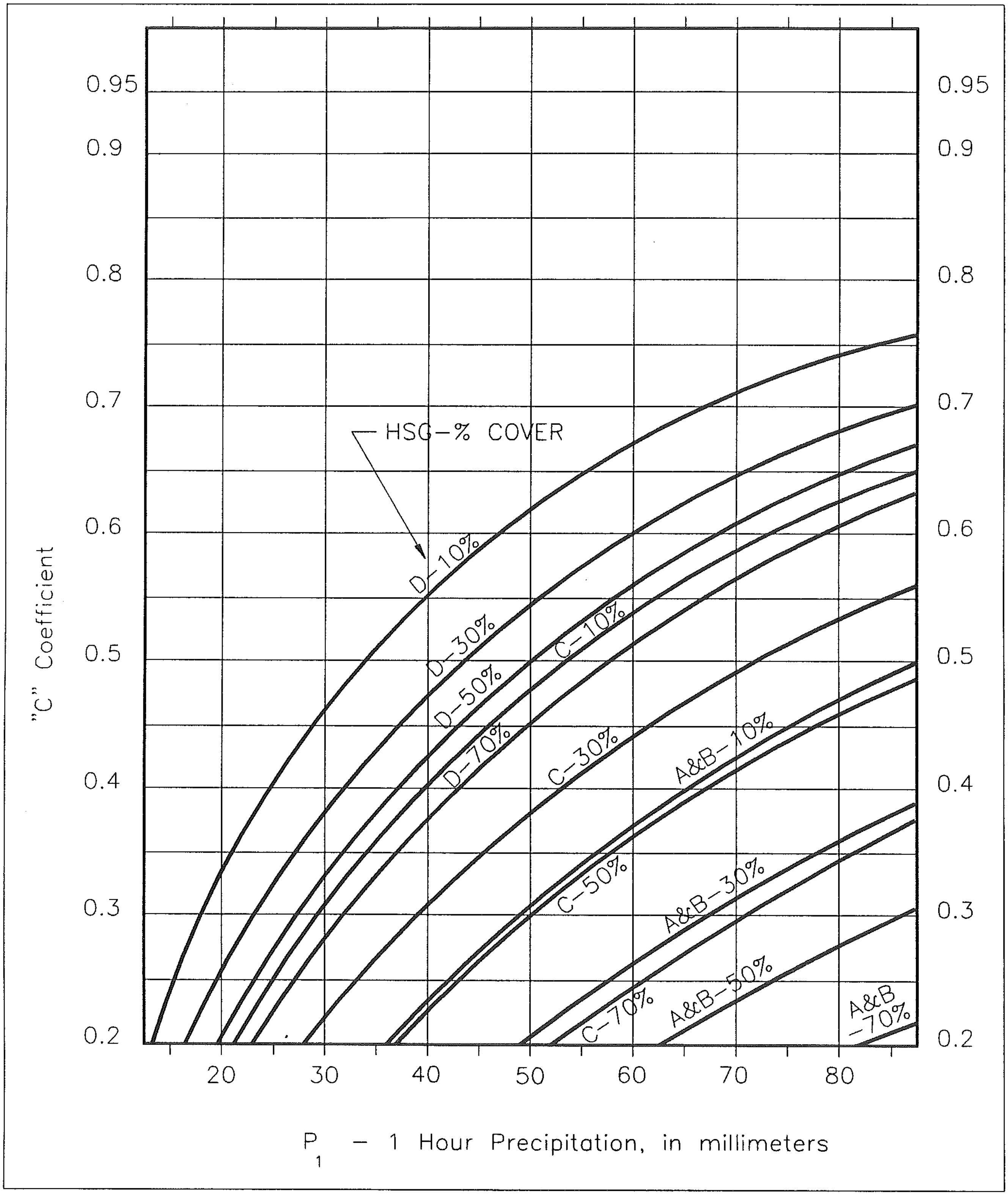


FIGURE 2-6
RATIONAL "C" COEFFICIENT
MOUNTAIN
(GRASS & BRUSH)

AS A FUNCTION OF RAINFALL DEPTH, HYDROLOGIC SOIL GROUP (HSG), AND % OF VEGETATION COVER

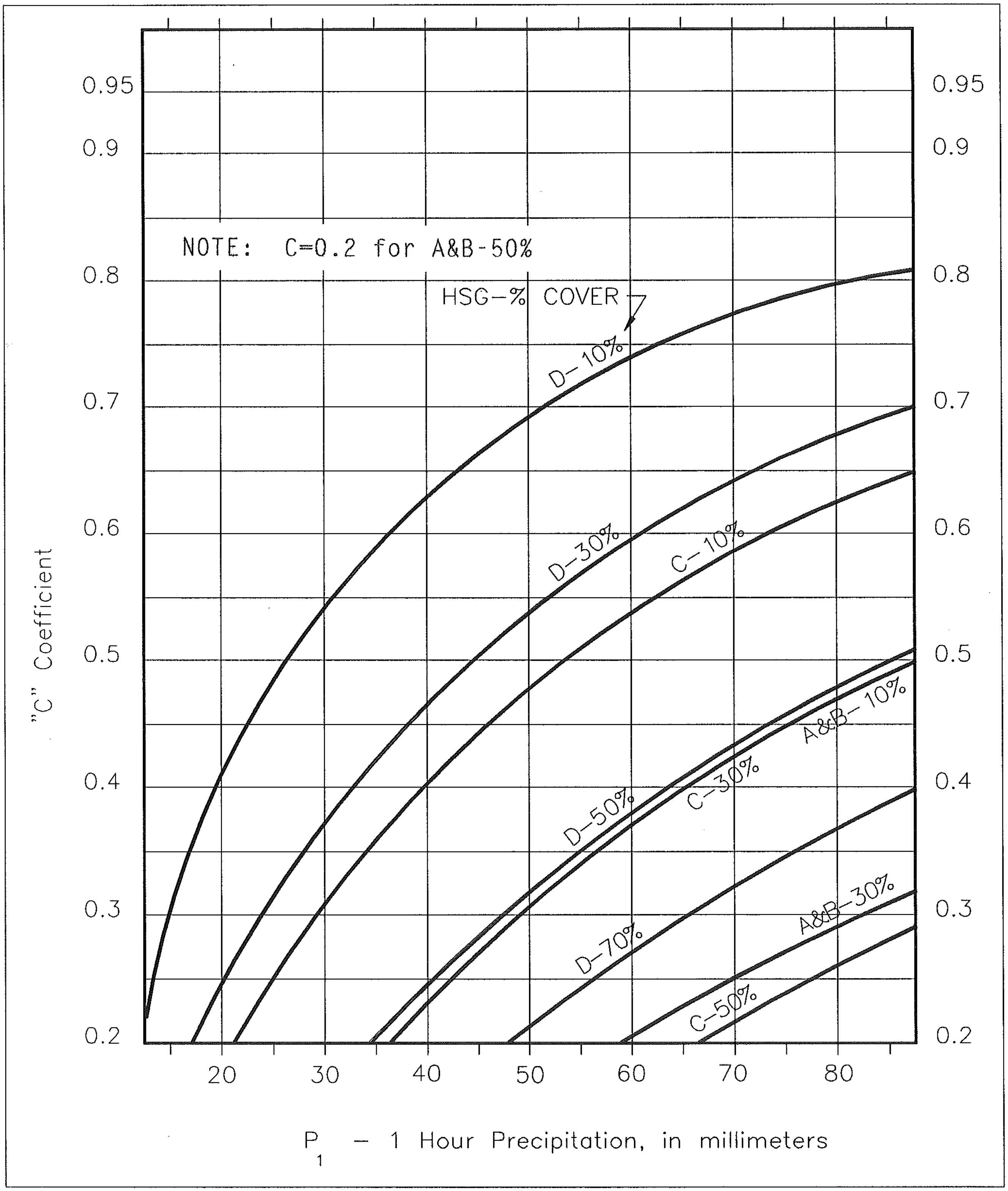


FIGURE 2-7
RATIONAL "C" COEFFICIENT
MOUNTAIN
(JUNIPER & GRASS)

AS A FUNCTION OF RAINFALL DEPTH, HYDROLOGIC SOIL GROUP (HSG), AND % OF VEGETATION COVER

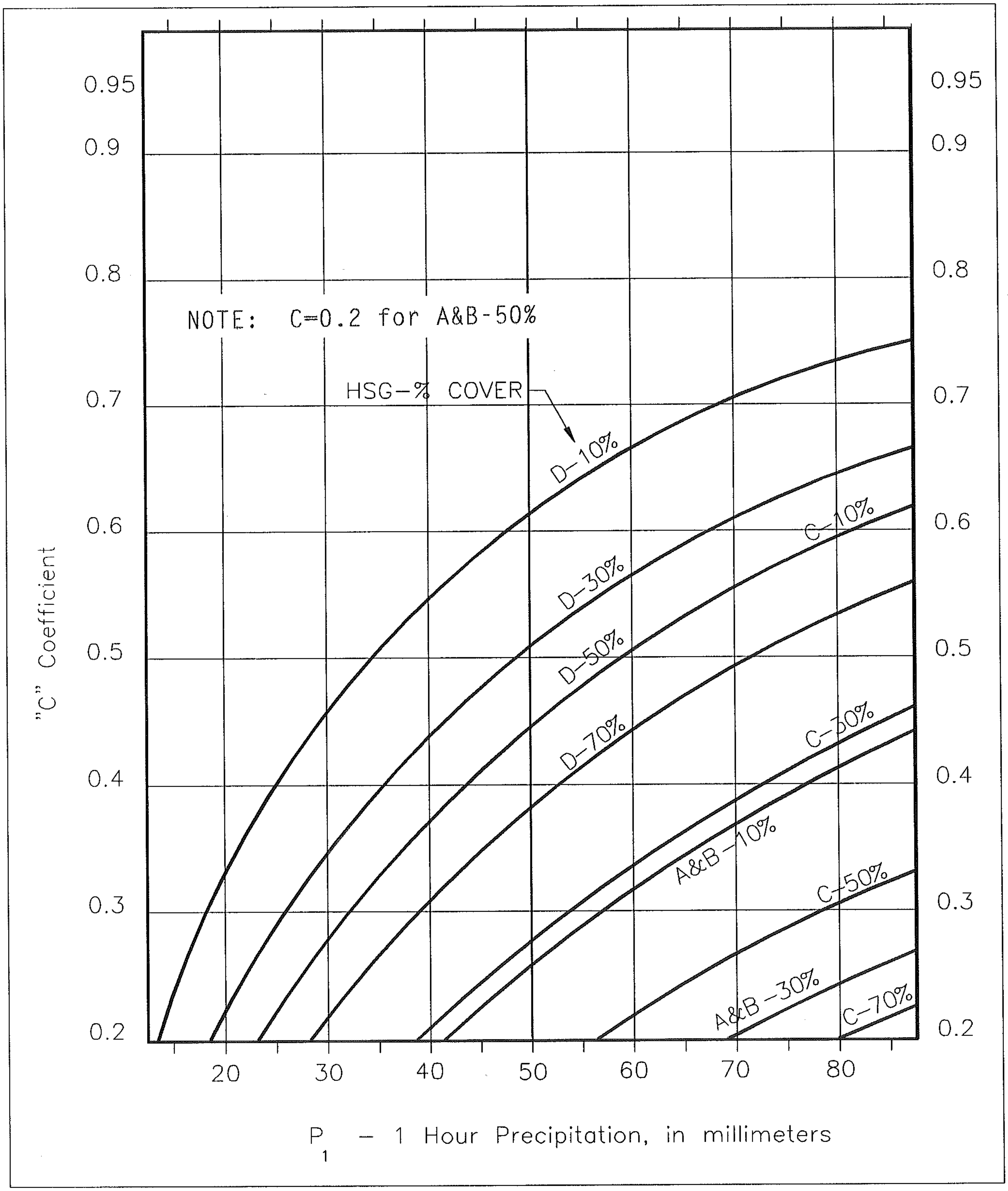
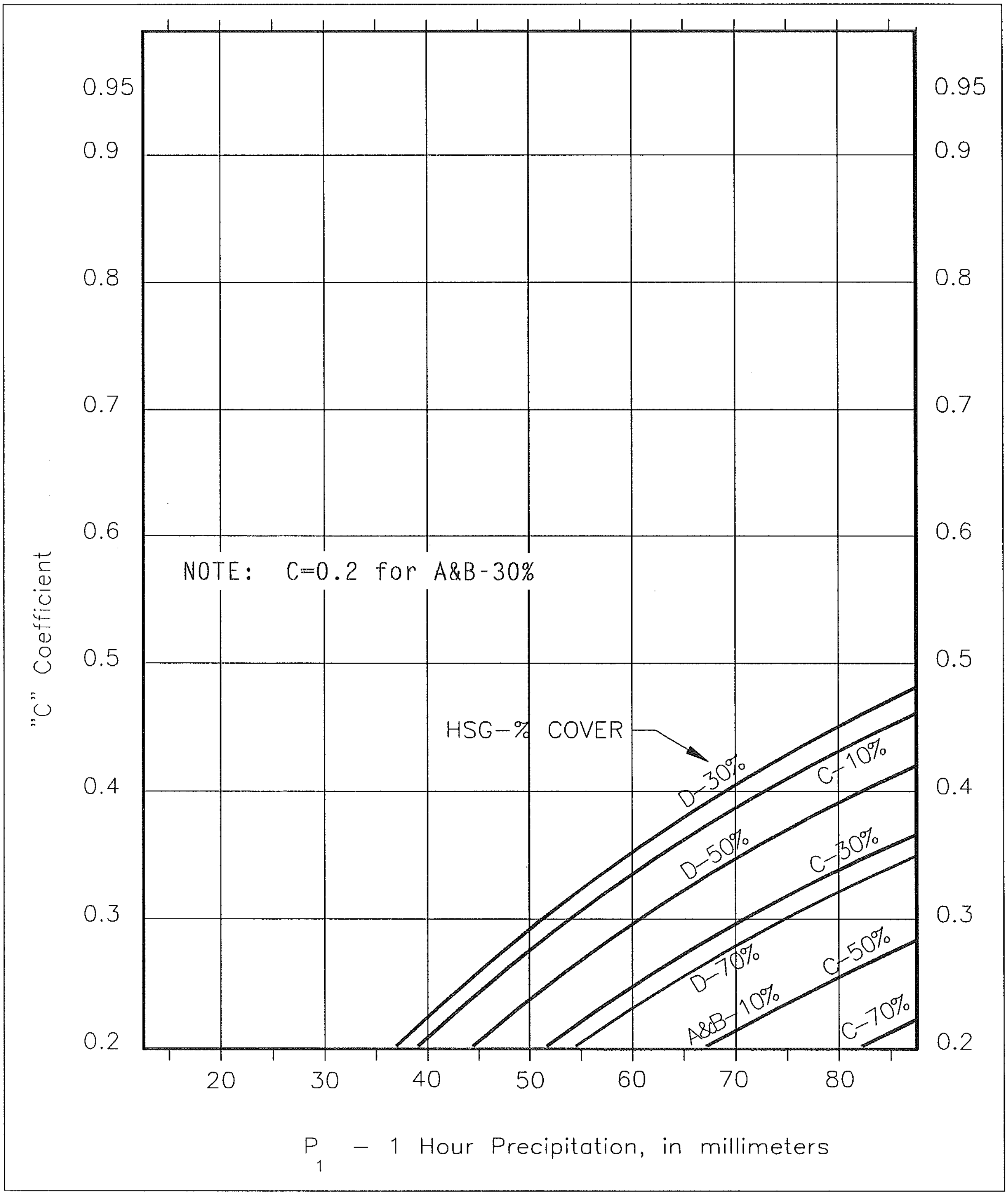


FIGURE 2-8
RATIONAL "C" COEFFICIENT
MOUNTAIN
(PONDEROSA PINE)

AS A FUNCTION OF RAINFALL DEPTH, HYDROLOGIC SOIL GROUP (HSG), AND % OF VEGETATION COVER



Problem:

Calculate the 100-year peak discharge and estimate the runoff hydrograph for a 25 hectare, single-family residential (about 20% effective impervious area) watershed in Phoenix. The following are the watershed characteristics:

A = 25 hectares

S = 5m/km

L = 1 km

The following were obtained for the watershed:

P_1 = 62.5 mm (converted from NOAA Atlas data, Appendix B)

K_b = .025 from **Table 2-1**

C = .65 from **Figure 2-3**

Solution:

This example is solved using A) a site-specific I-D-F graph, and B) using the generalized I-D-F graph.

A) Using the site specific I-D-F graph (shown):

Solve for T_c :

$$T_c = 18.3\ L^{Q5}\ K_b^{.52}\ S^{-.31}\ i^{-.38}$$

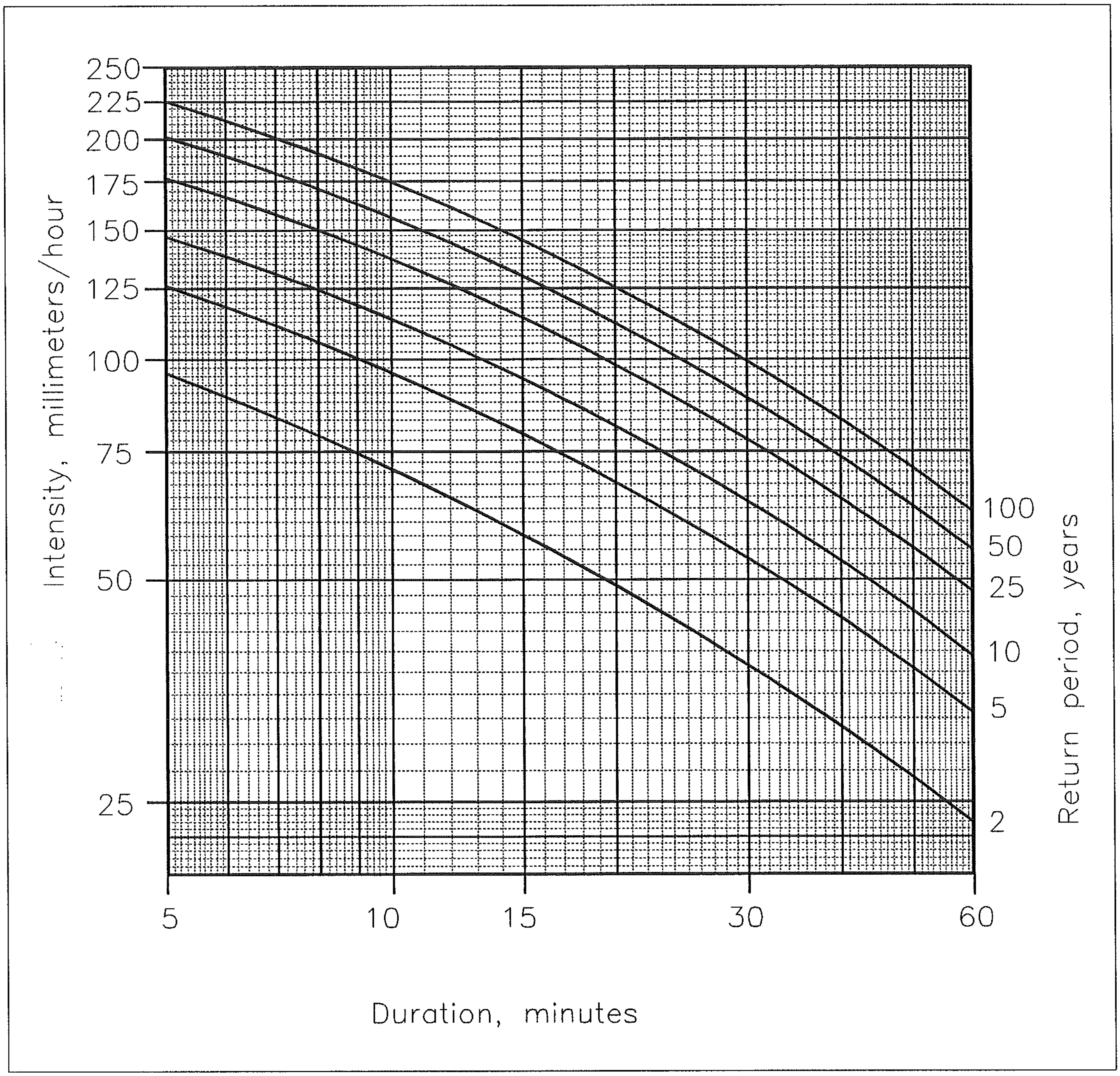
$$T_c = 18.3\ (1^{Q5})\ (.025^{.52})\ (5^{-.31})\ i^{-.38}$$

$$= 1.63\ I^{-.38}$$

Trial T_c, hr	i,mm/hr	Calculated T_c, hr
.75	77	.31
.30	133	.25
.24	148	.24 OK

EXAMPLE 2-1

RAINFALL INTENSITY-DURATION-FREQUENCY



Calculate Q:

$$Q = C\,i\,A\,/363$$
$$= (0.65)\,(148)\,(25)\,/363$$
$$= 6.6\ m^3/s$$

B) Using the generalized I-D-F graph (**Figure 2-2** for Zone 8):

Solve for T_c:

$$T_c = 1.63\,i^{-.38}$$

Trial T_c, hr	i,mm/hr	Calculated T_c, hr
.33 (19.8 minutes)	130	.25
.24 (14.4 minutes)	156	.24 OK

Calculate Q:

$$Q = C\,i\,A\,/363$$
$$= (0.65)\,(156)\,(25)\,/363$$
$$= 7.0\ m^3/s$$

The hydrograph shape is calculated using the Q that was calculated using the generalized I-D-F graph.

EXAMPLE 2-1

Estimate the hydrograph shape:

Use the urban, dimensionless hydrograph from **Table 2-2** for T_c = .18 to .25 hr.

q_{tmax} = 800

$$K = \frac{Q}{q_{tmax}} = \frac{7.0}{800} = .009$$

Tabulated Time hr	Dimensionless Hydrograph q_t m^3/s	Runoff Hydrograph $q_i = Kq_t$ m^3/s	Average Discharge $\frac{q_i + q_i + 1}{2} = \bar{q}$ m^3/s	Volume Calculation $\bar{q}$ (Δt) $m^3/s{\cdot}hr$
1.0	23	0.20		
1.3	31	0.27	0.24	0.07
1.6	47	0.41	0.34	0.10
1.9	209	1.83	1.12	0.34
2.0	403	3.53	2.68	0.27
2.1	739	6.47	5.00	0.50
2.2	800	7.00	6.73	0.67
2.3	481	4.21	5.60	0.56
2.4	250	2.19	3.20	0.32
2.5	166	1.45	1.82	0.18
2.6	128	1.12	1.29	0.13
2.7	102	0.89	1.01	0.10
2.8	86	0.75	0.82	0.08
3.0	70	0.61	0.68	0.14
3.2	61	0.53	0.57	0.11
3.4	54	0.47	0.50	0.10
3.6	49	0.43	0.45	0.09
3.8	44	0.39	0.41	0.08
4.0	40	0.35	0.37	0.07
4.3	35	0.31	0.33	0.10
4.6	33	0.29	0.30	0.09
5.0	30	0.26	0.28	0.11
5.5	27	0.24	0.25	0.12
6.0	24	0.21	0.22	0.11
6.5	21	0.18	0.20	0.10
7.0	20	0.18	0.18	0.09
7.5	19	0.17	0.17	0.09
8.0	18	0.16	0.16	0.08
9.0	16	0.14	0.15	0.15
10.0	13	0.11	0.13	0.13
12.0	12	0.11	0.11	0.22
16.0	0	0.00	0.05	0.21
				5.5 m^3/s-hr (19,850 cubic meters)

EXAMPLE 2-1

PEAK DISCHARGE